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ART. X.—*Isothermals, Isopiestics and Isometrics relative to Viscosity*;* by C. BARUS.

1. *Historical.*—In the following paragraphs, I endeavor to give a preliminary account of what may be called the isothermals, the isopiestics, and the isometrics with respect to viscosity. Notwithstanding the great geological importance† of these relations, nobody has as yet attempted to represent them systematically.

2. *The Material chosen.*—In order to obtain pronounced results for the effect of pressure on viscosity, substances must be selected on which temperature has a similarly obvious effect. For, in addition to the direct access to the molecule which is beyond the reach of pressure, temperature has the same marked influence on the expansion mechanism per unit of volume increment as the other agency. Hence liquids like marine glue, pitch, etc., which change continuously from solid to liquid, and in which this change takes place at an enormously rapid rate and is complete within relatively few degrees, are especially available for the present investigation.

The following data refer to *marine glue.* Viscosity is considered as a physical quality, and apart from such chemical considerations as are introduced in passing from one body to another. I must state, however, that the marine glue can be made to change its viscosity permanently, by cautiously heating it for different lengths of time. Thus I obtained charges

* Enlarged from a note in the Proc. American Acad., January, 1892.

† As has been indicated by Mr. Clarence King, in this Journal for January.

in which, at the same temperature and pressure, the larger viscosities were three or even five times as high as the smaller viscosities, and my work is therefore to this extent independent of the material operated on. Finally marine glue has the advantage of being both adhesive and tenacious, and errors due to slipping (§ 5) are thus reduced as much as possible.

3. *Definitions.*—In my paper* on the absolute viscosity of the three states of aggregation, I defined a fluid (liquid or gas) as a body which, under constant conditions of pressure, temperature, and stress, shows constant viscosity as to time. In a solid *ceteris paribus*, viscosity markedly increases with the time during which stress is brought to bear. The molecular instabilities of a liquid, therefore, are supplied at the same rate in which they are used in promoting viscous motion. In a solid they are used more rapidly than the small rate of continuous supply.

The point of essential concern in these definitions is the constancy of stress, and its value below a certain critical datum. For instance, if in a solid stress be *increased* at the (small) rate necessary to insure a constant supply of instabilities, then solid viscosity will also be constant, and I am by no means sure that in such a case† yield points would eventually present themselves as breaks in the continuity of the solid flow.

On the other hand stress may be conceived to increase so fast, that even a liquid fails to present sufficient instabilities for truly viscous motion. The elasticity and brittleness of many viscous liquids, especially at low temperatures, is a case in point.

4. *Hardness.*—Throughout my work on viscosity,‡ I have adverted to the association of viscosity with zero forces acting for infinite times, and of hardness with infinite forces (relatively) acting for zero times, and have adduced many new examples showing the distinctiveness of these two properties. The subject of hardness has, however, recently taken more definite shape in the researches of Auerbach,§ based on a principle due to Hertz.‖ According to these observers, hardness is an expression for the elastic limits of a body in case of contact between its plane surface and the curved surface of some other (harder) body. Hardness so defined admits of absolute measurement in terms of dynes per square centimeter.

5. *Method of Work.*—In all experiments like the present, one cannot be too careful to preconsider the conditions under

* Phil. Mag., V, vol. xxix, p. 337, 1890. Cf. p. 354.

† Cf. this Journal, III, vol xxxiv, p. 19, 1887.

‡ Phil. Mag., V, vol. xxvi, p. 210, 1888. Cf. Bull. U. S. Geolog. Survey, No. 73, pp. 42–44, 97, 98, 1891. See § 6 below.

§ Auerbach, Wied. Ann., vol. xliii, p. 61, 1891.

‖ Hertz, Crelle's Journal, vol. xcvi, p. 156, 1882.

which the results are obtained; for one is only too apt to attribute an absence of flow to the effect of pressure on viscosity, when the real cause is to be found in the geometry of the apparatus employed. I have therefore availed myself of transpiration methods, since the theory of the experiments is in this case very fully given.

The marine glue, § 2, was forced out of a sufficiently large reservoir, through tubes of steel about 10^{cm} long, and 0·5 to 1^{cm} in diameter, cf. figure 1. Pressures as high as 2,000 atm. were applied at the reservoir, by aid of my screw compressor.* Temperatures between 10° and 30° were kept constant by a suitable water bath. Throughout the work the flow was so excessively slow (amounting to an advance of only a few millimeters per hour), that Poiseuille's law was at once applicable. The only considerable source of error in the work is the occurrence of more or less incidental slipping. However, inasmuch as the outflow of marine glue is capped by a rounded surface, it follows that the flow is most marked at the axis of the tube compatibly with the theory of the experiment. Methods of charging, manipulation, etc., must here be omitted.

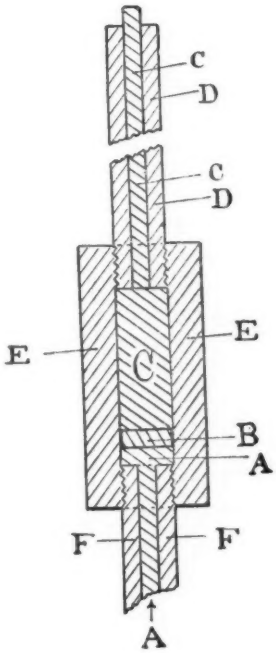


Figure 1.—Sectional elevation of the high pressure transpiration apparatus. Scale ½. *E*, steel reservoir; *D*, steel transpiration tube; *C*, charge; *B* movable solid disc; *A*, compressed oil forced in through the tube *F*.

6. *Volume Viscosity*.—At the end of stated intervals of time (usually hours), the small cylinders of marine glue which had exuded were cut off in the plane of the top of the tube with a sharp knife, and weighed. Now it was curious to note that these cylinders, left to themselves for about a day, showed a gradual and marked deformation, such that the originally plane bottom or surface of section eventually expanded into a symmetrical projecting conoid, with an acute apex angle of less than 45°. I take this to be an example of volume viscosity, inasmuch as an expansion gradually increasing at a retarded

* Phil. Mag., V, xxx, p. 338, 1890.

rate in the lapse of time, is the chief feature. The case, however, is much more complex, for the restitution of volume is greatest in the axis of cylinder where the flow is a maximum, and it is accompanied by a series of distortions of the kind given in figure 2. Here *G* shows the shape of the cylinder or button immediately after cutting it off of the column *H*, surrounded by the steel transpiration tube. After 24 hours, when both were left free from pressure, *G* passed into the form *I*, and *H* into *K*. The emergence of the cone begins visibly, soon after cutting. After long waiting, a cavity sometimes dimples the top of the button as shown at *L*. I have also obtained cup-shaped deformations, like *M*. The height of the projecting cone bears no obvious relation to the length of the cylinder. Thus on flat buttons ·6^{cm} in diameter and less than ·4^{cm} high, the apices of the conoids will often be at a distance of ·3^{cm} and ·4^{cm} from the geometric base.

Figure 2.—Sectional diagrams, showing the elastico-viscous deformations of exuded cylinders of the charge *C*, Fig. 1, external pressure being zero.

In general, therefore, the originally plane right sections of the transpiring column tend to become plane after stress ceases; or plane right sections of the axially stressed column, tend to bulge out conoidally, symmetrically around the axis, and in a direction opposite to that of the stress, when stress ceases. Thus the experiment points out in a beautiful way how much residual viscosity resembles a slowly reacting elasticity.* Complete restitution of form cannot occur because of the dissipation of energy.

7. *Viscosity and Pressure.*—Inasmuch as marine glue is a nonconductor and highly viscous, much time must be allowed before temperature and pressure can be assumed to have penetrated the mass uniformly. Again whenever the oil of the compressor accidentally reaches the transpiration tube, the slip error is enormously increased and the results are worthless. A single charge will not therefore outlast many experiments. These are the chief reasons why much time has to be spent on the work and why it is difficult to coördinate the results. Another annoyance is the unavoidable lack of homogeneity of the charge, and the possibility of a reservoir correction. It will therefore be expedient to briefly indicate the method by which trustworthy results were eventually reached.

* A suggestive example of the gradual passage of true elasticity into true viscosity is given by the phenomena observed on stretching a string of (dry) vulcanized india rubber deposited from solution. If the string be suddenly released, elasticity and viscosity appear as the two extreme phases of contraction, terminating a continuous series of intermediate phases.

Table I gives an example of my earlier results. The transpiration tubes were *smooth* internally as shown in figure 1.

The table is one of double entry, and the data contained show the absolute viscosity (η) of marine glue at the stated temperatures and pressures, in terms of one billion g/cs units. The pressure excess is the difference of pressures at the two ends of the tube.

TABLE I.—Mean Values of $\eta/10^9$ for Marine Glue.

Δp = Pressure Excess	100 atm.	300 atm.	1000 atm.	1500 atm.	2000 atm.
Temperature = 8·5°	....	....	>30 000	12·0	>60 000
" = 18·3°	(2·5)	....	8·30	12·0	15·2
" = 22·5°	....	....	1·12	....	2·2
" = 30·5°	·065	·073	....	....	....

Rates at	18·3°	22·5°
$10^{-9} \times \Delta\eta/\Delta p$ =	·0137	·00220
$b = \Delta\eta/\eta_0 \times \frac{1}{2}\Delta p$ =	·0091	·020

In constructing the rate of change of viscosity with pressure, I assumed that the whole thread *transpired at the mean of the pressures at the two ends of the steel tube;* or since the pressure at the open end is zero, at half the pressure excess. Furthermore, that

$$\eta_p = \eta_0(1 + bp) = \eta_0(1 + \tfrac{1}{2}b\Delta p)$$

If therefore $\Delta\eta$ be the increment of viscosity corresponding to the pressure $\frac{1}{2}\Delta p$, the final data of Table I (rates) are at once intelligible.

What is chiefly striking in this table is the preponderating influence of temperature. Thus the material, which between 20° and 30° C. transpires readily enough, is at 8° so nearly solid, that a burden of 2000 atmospheres, brought to bear at one end of a transpiration tube 10^{cm} long and as wide as 1^{cm}, is unable to produce perceptible flow even after 5 hours. It also appears that *in proportion as the viscosity of a body increases with fall of temperature, its isothermal rate of increase with pressure also increases.*

Some time after, I repeated this work with great care and obtained—

Temperature =	1·8°	·20°	·22°	·24°
$\eta_0 10^9$ =	2·7 } 5·2 }	4·3	·94 } 1·16 }	·28
$b \times 10^3$ =	8·0 } 3·0 }	1·3	3·9 } 1·8 }	4·8

It would be premature to speculate on the nature of the relation of viscosity to pressure and to temperature, on the basis of these results. As to the pressure coefficient b, one

can only infer that its value is of the order of ·005, and that it bears no obvious relation to the initial viscosity, or to temperature.

In endeavoring to improve upon this work I cut a screw thread in the *inside* of the transpiration tube and thus largely obviated slipping, by compelling the charge to flow on itself. I also made all observations in triplets, including each measurement at a high pressure or temperature between two fiducial measurements at a given lower pressure or temperature. Only such observations were taken for which the fiducial data were identical. Finally by treating the charges individually, I found that although the viscosities at the same temperature were very different, the pressure coefficients followed each other in the order of the initial viscosities.

Experiments made in this way showed—

Temperature	=	16·5°	13·9°	11·9°	18·0°	15°	15°	20°
$\eta_0/10^9$	=	·50	2·15	2·50	·70	3·7	3·7	·40
$b\times10^3$	=	4·2	4·3	8·9	5·3	4·6	4·8	6·5

These are the best results I have been able to obtain. How nearly linear the variation of viscosity with pressure is, may be seen in the following example of consecutive measurements:

Pressure excess Δp	=	340	700	1055	1410	1770	340	*atm.*
Viscosity, $\eta/10^9$	=	·87	1·20	1·60	2·07	2·30	·87	*gcs*

Even in case of high viscosity ($>10^{10}$), a tendency of viscosity to increase at an accelerated rate with pressure is only vaguely apparent, e. g.,

Pressure excess, Δp	=	505	1020	505	1540	1022	1540	*atm.*
Viscosity, $\eta/10^9$	=	8·4	12·6	7·9	17·9	12·9	17·1	*gcs*

Taking the above work as a whole, therefore, I am bound to infer that within the range of observation (2000 atm.), the pressure coefficient is constant: for though varying between ·004 and ·009, it shows no discernable relation to the initial viscosity (η_0 for $\Delta p = 0$), or to temperature. In other words, to assume that the rate at which viscosity increases with pressure at any temperature, is proportional to the initial viscosity at that temperature, is the nearest approach to the actual state of the case which my observations enable me to make. Taking the mean of all values in hand I thus obtain—

$$\eta_{\theta,\,p} = \eta_{\theta,\,0}(1 + \cdot0057\ p) \qquad (1)$$

where the subscripts show the temperature (θ) and pressure (p) at which viscosity (η) is taken; and where p is the mean of the pressures at the two ends of the transpiration tube.

8. *Viscosity and Temperature.*—It is next in place to find a suitable expression for the relation of viscosity to temperature. Contrary to my expectations this was comparatively easy; and the reason seems to be that so long as pressure is constant, the error due to slipping is less liable to change. An example of the results worked out from triads as above, and obtained with screw tubes is given in the following tables. $\Delta p = 505$ *atm.*

	Observed.	Computed.			Observed.	Computed.	
Temperature	$\eta/10^9$	$\eta/10^9$		Temperature	$\eta/10^9$	$\eta/10^9$	
12°	7·70	7·78	$A=11\,895$	15°	8·15	8·13	$A=12{\cdot}385$
14°	3·75	3·61	$B=\ {\cdot}167$	17°	3·82	3·80	$B=\ {\cdot}165$
16°	1·61	1·67	$\eta_0=7{\cdot}8\times10^{11}$	19°	1·72	1·78	$\eta_0=2{\cdot}4\times10^{12}$
				21°	·81	·83	
				23°	·42	·39	

It is seen at once that within the range of observation (12°–16° C., 15° to 23° C.) temperatures increase in arithmetical progression while viscosities decrease in geometrical progression. Hence (2) $\log \eta_{p,\theta} = \log \eta_{p,0} - B\theta$, and the factor B has the large value, ·165. Of the two sets of data given, the initial viscosity, $\eta_{p,0}$ is fully three times larger in one case than in the other. Nevertheless the quantity B is practically the same in both. For this reason I shirked the great labor attending experiments at higher pressures and concluded conformably with the suggestions of the preceding paragraph, that as a first approximation the rate at which viscosity increases with temperature at the temperature $\theta°$, is proportional to the viscosity at $\theta°$, and is independent of pressure.

9. *Summary and chart.*—With the principle thus laid down I am able to give a graphic exhibit of the isothermals and the isopiestics. This is done in the chart, figure 3, where the ordinates are absolute viscosities, and the abscissas, pressures and temperatures respectively. The isopiestic for $p = 250$ atm. is directly observed between 15° and 23°. The other curves are computed from this by aid of the coefficients deduced in §§ 7, 8. The range as a whole may be taken as that of the present experiments. The (computed) initial viscosity $\eta_{0,0}$ (for $p = 0$ and $\theta = 0$) is very nearly 10^{12}. As usual $p = \Delta p/2$.

10. *Isometrics.*—From these data the isometrics may be constructed graphically and in this way the curves marked η were obtained. I am now able to answer some important questions as to how temperature and pressure must vary, in order that viscosity may remain constant. Equations (1) and (2) lead easily to

$$(dp/d\theta) = (ln\ 10)\, B(1+bp)/b \qquad (3)$$

Hence the isometrics are all identical as to contour and ob-

tained by dropping the initial curve over stated amounts. For any viscosity and at any temperature within the range of observation, therefore, the increment of pressure which will just annul the decrement of viscosity due to a rise of temperature of one degree Centigrade is, for instance,

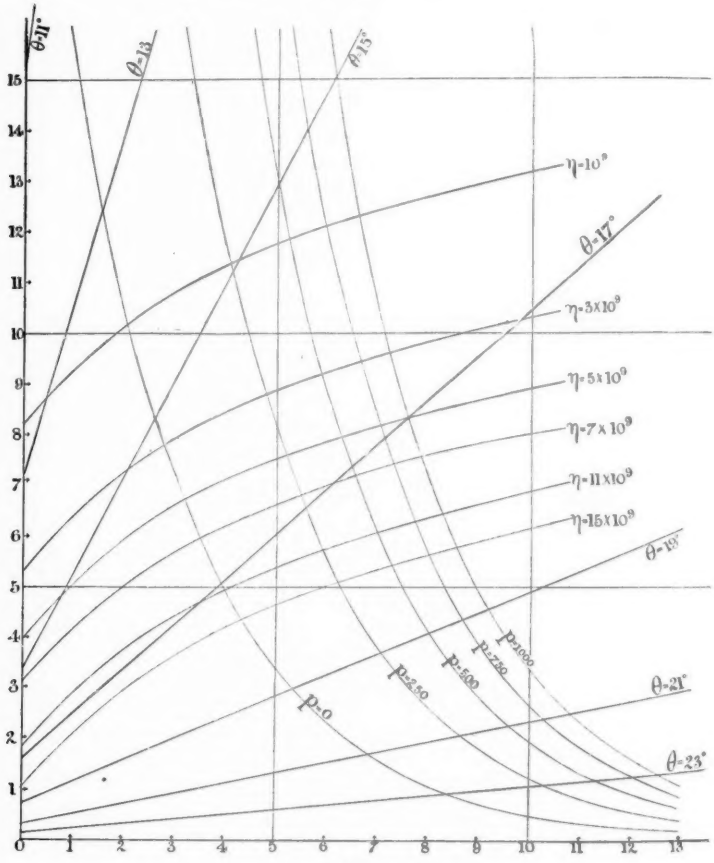


Fig. 3.

Fig. 3.—Chart showing the isothermals (θ), the isopiestics (p), and the isometrics (η), relative to the viscosity of marine glue.

Abscissas: Pressure in *hundreds* of atmospheres, or in *two hundreds* of atmospheres of pressure excess.

Temperatures in degrees Centigrade beginning with 10° C.

Ordinates: Viscosities in *billions* of absolute (g/cs) units.

Temperatures in degrees Centigrade beginning with 10° C.

Pressure	=	0 atm.	500 atm.	1000 atm.
Increment of pressure	=	67 atm.	256 atm.	380 atm.

and so on. Thus the relative inefficiency of pressure as compared with temperature is apparent, though to make the comparison just, both agencies should be taken per unit of volume increment. Cf. § 11.

11. *Digression, Logarithmic isothermals.*—Believing that the error due to slipping increases with pressure, i. e. in proportion as the charge becomes more solid, and noting the tendency (§ 7) of isothermals for high viscosity to slope upward, I thought it worth while to compute the isothermals on the supposition that $\log \eta = a' + b'p$, as an extreme case. Necessarily, marked violence is thus done to the observations, and b' obtained from high pressures must be smaller than b' from low pressures. Preferring the latter, I found, for instance

$\eta_0/10^9$	=	·69	5·9	4·7	2·9	·64
$b' \times 10^5$	=	81	73	93	73	74

As before a dependence of b' on η_0 does not appear and $b' =$ ·00078 may be taken as the mean value.

The interest which attaches to this case is its bearing on the isometrics, which now appear as straight lines. For if

$$C = \eta_{\theta p}/\eta_{\infty}, \log C + B\theta = b'p, \text{ and } (dp/d\theta) = B/b' = 210$$

In other words 210 atm. would annul the decrement of viscosity produced by a rise of temperature of 1° C., at all temperatures and pressures.

Seeing that in an elegant research of Ramsay and Young,* and in high pressure work† of my own, the volume isometrics of liquids appear as straight lines, the present considerations may possibly claim more than passing comment.

The immediate object of the present paragraph, however, is to give warrant to the statement, that in high pressure phenomena *at least* 200 atm. must be allowed per degree Centigrade, in order that there may be no change of viscosity.

12. *Maxwell's theory.*—If for the sake of definiteness, viscosity (η) be defined as proportional to the ratio $(N-n)/n$, of the number of stable configurations $(N-n)$, to the number of unstable configurations (n), in a given volume, then the above expressions may easily be translated into the language of Maxwell's theory of viscosity.‡ I shall therefore withhold further remarks here. The conditions are simplified since for

* Ramsay and Young: Phil. Mag., xxiii, p. 435, 1887; xxiv, p. 196, 1887.

† Barus: Phil. Mag., xxx, p. 338, 1890.

‡ This was done in my note in this Journal for September, p. 255.—In the series, atom, molecule, viscous configuration, the last can not be as sharply defined as the other two, and only the former as yet admits of generic classification (periodic law). Cf Am. Chem. Journ., xiv, pp. 197–201.

a substance like marine glue, n is probably small as compared with N.

13. *Measurement of excessively high pressure.*—Let there be given a tube of length l and radius ρ. Let $\eta = \eta_0(1+bp)$ be the viscosity of the viscous liquid forced through it by the pressure excess $\Delta p = 2p$ (so that there is no pressure at one end of the tube), and at the constant temperature θ. The length (λ) of a cylinder of fluid issuing per unit of time (t) will then be $\rho^2\Delta p/8l\eta_0(1+b\Delta p/2)$. Hence if negative pressures be excluded, the function λ/t is of a kind which continually increases with Δp, a state of the case which would not be true if the expression of § 11 were applicable.

In view of the observed property of λ/t, it is worth inquiring in how far the transpiration method is available for high pressure measurement, when most other means fail.

Take for example a tube $\frac{1}{16}$ inch in diameter and 1 inch long. Then the mass m of the above marine glue which at say 18° would exude per hour is

$m\times10^6$ =	5970	7550	7810	7900	7950 *grams.*
Δp =	1000	5000	10000	15000	20000 *atm.*

where $\eta = 10^9(1+\cdot00285\Delta p)$.

Thus it appears that whereas a hole $\frac{1}{16}$ inch in diameter may be efficiently sealed by marine glue at 18° C., pressure measurement by aid of the exuding mass is impossible above 10,000 atm., whereas even between 5000 atm. and 10,000 atm. the method is insensitive. To use a method like the present for very high pressure measurement, a substance of smaller pressure coefficient must therefore be sought, if such a one with other necessary qualities, exists. It is with the object of searching for such a body, as well as of finding the maximum of hydrostatic pressure attainable in the laboratory that I had a tinned screw and socket constructed,* and hope to be able to report the results of my work at an early opportunity. To my knowledge the only other gauge available under the circumstances is the one I based on the resistance of mercury. It is sufficient, however, for making the comparisons in question.

Phys. Lab. U. S. Geolog. Survey, Washington, D. C.

* Proceed. American Acad., xxv. pp 94, 108, 1890.

Art. XI.—"*Potential*" *a Bernoullian Term;* by Geo. F. Becker.

Potential as the name of a function was undoubtedly introduced by Gauss in 1840. He wrote: "Zur bequemern Handhabung der dazu dienenden Untersuchungen werden wir uns erlauben dieses V mit einer besondern Benennung zu belegen, und die Grösse das *Potential* der Massen, worauf sie sich bezieht, nennen."* But Gauss was certainly not the first to employ the corresponding adjective in a similar sense. George Green employed the term *potential function* in 1828 in his famous paper on electricity and magnetism. He introduced the phrase by remarking that certain memoirs of Poisson's "are in fact founded upon the consideration of what have, in this essay, been termed potential functions."† In section 1 of the paper he says: "As this function . . . will occur very frequently in what follows, we have ventured to call it the potential function belonging to the system." Nowhere in this paper can I find the word potential used as a noun, while "potential function" is met with on almost every page.

Most physicists give Gauss full credit for independent investigation of the potential, but Todhunter refers to the matter in a manner which would seem to convey an innuendo. "We may observe," he says, "that the name *Potential* was first used by the late George Green. . . . Gauss used the word in his memoir . . . published in 1840. As Gauss does not refer to any previous authority we are, I presume, to infer that he had independently selected the name."‡ As was pointed out above, this is not a correct statement, since Green did not use the *name* potential but only the adjective; and the effect of the words "I presume" is to suggest a doubt whether Gauss might not have been acquainted with Green's nomenclature, and consequently also with the theory portions of which he is credited with rediscovering. Gauss however never displayed any tendency to plagiarism.

It is not very generally known, though it has been mentioned in modern literature, that Daniel Bernoulli and Euler employed the term *vis potentialis.* A single passage from Euler will illustrate its use: "Quamobrem cum vir celeberri-

* Allgemeine Lehrsätze in Bez. auf . . . Anziehungs- u. Abstossungs-Kräfte. Collected works, vol. v, 1867, p. 200.

† Reprinted in Crelle's Journal, vol. xxxix, p. 77, 1850, and in his collected papers.

‡ Math. hist. theories of attraction and the figure of the earth, vol. ii, 1873, p. 26.

mus . . . Daniel Bernoulli mihi indicasset se universam vim, quae in lamina elastica incurvata insit, una quadam formula quam *vim potentialem* appellat complecti posse, hancque expressionem in curva elastica minimam esse oportere, etc." In stating his problem he says again "atque, secundum Bernoullium, exprimetur *vis potentialis* in laminae portione AM contenta hac formula $\int \frac{ds}{RR}$," s being the arc of the spring and R the radius of curvature.* It is evident that in these passages *vis* is used in the same sense as in *vis viva* and that it is to be translated energy, so that Bernoulli's proposition was that the elastic curve must be such as to make something which he regarded as the potential energy of a bent spring a minimum.

Todhunter in his History of Elasticity, 1886, quotes passages from D. Bernoulli's letters in 1742–3, in which the vis potentialis is mentioned; but since the historian makes no allusion to his earlier remarks on the origin of the name Potential, it must be inferred that no relation between the two terms suggested itself to him. Had Todhunter lived to edit his history, perhaps this omission would have been supplied.

It is well known that Green's great memoir was not published in the ordinary manner, but by subscription in Nottingham, and that it attracted no attention for many years either in Great Britain or on the Continent. Gauss was thus very naturally ignorant of it. On the other hand it is substantially impossible to suppose Gauss ignorant of the famous memoir of Euler quoted above. The methods there developed of finding curves have been superseded by those of the calculus of variations; but the appendix, *Additamentum de curvis elasticis*, from which the passage quoted above is taken, contains the classification of elastic curves into nine species which, so far as I am aware, has received no addition or improvement.

There can thus be substantially no doubt that Daniel Bernoulli's vis potentialis suggested to Gauss the name potential for a somewhat similar but more general function. Either he considered the change of form of the expression and the increased generality of its significance as sufficient to make any reference to Bernoulli needless; or, as seems more probable, he assumed that his readers were as well read as himself and that an allusion was superfluous.†

* De Methodis inveniendi lineas curvas maximi minimive proprietate gaudentes. 1744, pp. 246, 247.

† The potential has received a variety of names in modern times. "Force function," which seems to be used by European mathematicians at least as frequently as potential, was proposed by W. R. Hamilton in his famous memoir on varying action, Phil. Trans., 1834, p. 249. In the same year B. de Saint-Venant called it "latent dynamic capital" (Leçons de Navier, 1861, p. 786) and Ampère suggested "implicit vis viva." Ann. chim. phys., vol. lviii, 1835, p. 438.

It is natural to inquire what Euler and Bernoulli meant in terms of modern nomenclature by vis potentialis. Now Saint-Venant has pointed out* that if M is Young's modulus and J the moment of inertia of the cross section of the spring, the work done in flexure for a length s is

$$\frac{MJ}{2}\int_0^s \frac{ds}{R^2}$$

so that Bernoulli's function is simply proportional to the potential energy as that expression is now understood and to the *Potential*, a fact to which the great French elastician calls attention.

There seems to be a general impression that the natural philosophers of the last century, when they used the quantities now known as kinetic, potential and total energy at all, regarded them from a purely algebraical or geometrical point of view, failing to perceive their great physical significance. In this respect these physicists seem to have been underrated: as some passages from the first John Bernoulli, Euler's teacher and D. Bernoulli's father, will show. In a paper on the true conception of living forces† he generalizes the idea of vis viva and defines it as equivalent to capacity for doing work, or *facultas agendi*, which is simply a Latin equivalent of the Greek energy. In Section I of this paper he says (translated):

"Vis viva does not consist in the actual exertion, but in the capacity for doing work; for it subsists even when it does no work nor has any object whereon it could act; so for example a strained spring, or again a body in motion, has in itself the capacity of doing work, so that if nothing external to itself come in its way upon which it may exert itself, and so long as there is no object present with which it can come in contact, it infallibly retains it all undiminished by time, and does not do the work which it would be capable of doing if it had the opportunity."

This seems a clear and even a vivid statement of the law: "When a system is subjected to no external forces, its energy remains constant."

In Section III he takes a further step. "Vis viva (which would be more aptly named facultas agendi, gallice le pouvoir)‡

* Leçons de Navier, edition of 1864, p. cxij.

† De vera notione virium vivarum, Acta Eruditorum, Leipzig, 1735, p. 210.

‡ The term power is now rarely used for energy, but it is scarcely a generation since this meaning was common enough. Saint-Venant (op. cit., p. 785) in 1864 defined the potential of one or more forces as "leur pouvoir moteur total." B. Peirce in his great work on analytical mechanics 1865 always uses "power" instead of "energy."

is something real and substantial, which has an independent existence and, whatever it consists of, depends upon nothing else. Whence we conclude, that any given vis viva is of determinate quantity of which none can disappear except it reappear in the effect produced. Hence it follows at once, that vis viva is always preserved, and so perfectly that what inhered in one or many bodies before action is now, after action, necessarily found in another or in several others excepting what remained in the first system. And this we call the *conservationem* virium vivarum."

Compare this with the modern statement: In any system the variation of energy is equal to the external work done by the system less the work done by external forces upon the system.

John Bernoulli was under no misapprehension as to the importance of the principles he had stated. He says in substance: Whether bodies are regarded as communicating motion to one another or whether one considers the various modifications of the motion of one and the same body depending on its own force (where nothing can vanish without an equivalent effect), "pro fundamento et principio universali poni debet conservatio virium vivarum, hoc est illius *facultatis agendi*."

That such men as Daniel Bernoulli and Euler should have been deaf to teachings like these is impossible and they must therefore have had an idea of the vis potentialis differing but little from that which the words convey to modern ears.

It would be interesting to know whether they really omitted to show in any portion of their writings why they felt themselves at liberty to base investigations on the statement that the potential energy of a strained solid is a minimum. Indeed it appears to me that the few notes given above are sufficient to indicate an opportunity for a physicist to write a most interesting essay on the evolution of the potential up to the date of Lagrange's memoir on the movement of a number of mutually attracting bodies (1777) in which the potential seems to have been used for the first time in an entirely general form.

Washington, December, 1892.

Art. XII.—*Datolite from Loughboro, Ontario;* by L. V. Pirsson.

The crystals of datolite which are the subject of this note were sent to this laboratory for examination through the kindness of Messrs. English & Co., of New York. They had been forwarded to them by the owner and the occurrence is the

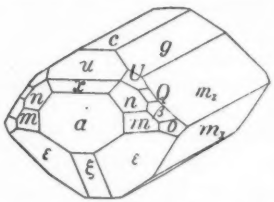
Lacy Mine, Loughboro, Ontario. More magnificent crystals of this species have probably never been found in America and they are equalled by few European specimens. They are pure and transparent with a yellowish green tinge and enclose only a few small crystals of chalcopyrite as impurities. At first glance they resemble large topaz crystals. In size they measure for the largest crystals $3 \times 2\frac{1}{2} \times 2^{cm}$. Nothing is known of the mode of occurrence save what can be gathered from the examination of a small amount of associated material on the hand-specimens. From this, the mineral seems to have formed in veins in a light colored igneous rock too much acted upon by fumarole agencies for satisfactory determination, but containing a considerable amount of a brownish biotite. On the specimens the datolite crystals are associated with quartz, calcite and chalcopyrite.

The material consisted of two hand specimens with groups of large crystals and one detached crystal of the size mentioned. In habit these crystals are nearly all alike in the development of their planes, being characterized by a prismatic like development in the zone of clinodomes following the orientation given this species by E. S. Dana.*

The loose crystal could be easily measured and was also the most complex in the development of its planes. The following forms were identified:

a (100) i-$\bar{1}$	u (104) $-\frac{1}{4}$-$\bar{1}$	n (111) -1
b (010) i-i	x (102) $-\frac{1}{2}$-$\bar{1}$	ε ($\bar{1}12$) $\frac{1}{2}$
c (001) O	ξ ($\bar{1}0?$) $\frac{1}{2}$-$\bar{1}$	β (121) $-2\grave{2}$
m (110) I	g (012) $\frac{1}{2}$-i	Q (122) $-1\grave{2}$
o (120) i-$\grave{2}$	m_x (011) 1-i	U (123) $-\frac{3}{2}\grave{2}$

This crystal is shown in the accompanying figure. All the faces except the pinacoids and clinodomes have been relatively exaggerated in size to exhibit them better. No other forms beyond these were observed on any other of the crystals. The zone o, β, Q, U was well developed and gave excellent reflections on the goniometer.



The crystals were not studied optically as no material was available without damage to the specimens, but, as confusion has frequently occurred in the orientation of this species owing to the great similarity of angles in the zones of prisms and of clinodomes, the following table of measured and calculated angles is appended to show the correctness of the orientation and the identification of the forms.

* System of Mineralogy, New York, 1892, p. 502 *et seq.*

The calculated angles are those from Dauber's* measurements from which we have the elements,

$$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}63446 : 1 : 1{\cdot}26574 \text{ aug. } \beta = 89° 51' 20''$$

		Calc.	Meas.		
$c \wedge u$	$001 \wedge 100$	89 51½	89° 36′		
$a \wedge m$	$100 \wedge 110$	32 23½	32 26½	32 26½	
$m_x \wedge m_x$	$011 \wedge 01\bar{1}$	76 37	76 37		
$a \wedge n$	$100 \wedge 111$	38 55	38 52	38 53	
$a \wedge m_x$	$100 \wedge 011$	89 55	89 50		
$c \wedge n$	$001 \wedge 111$	66 57	66 49		
$a \wedge x$	$100 \wedge 102$	45 0½	44 52		
$a \wedge u$	$100 \wedge 104$	63 22½	63 16		
$a \wedge \xi$	$100 \wedge 10\bar{2}$	45 08½	45 12		
$c \wedge g$	$001 \wedge 012$	32 19½	32 15	32 24	32 08
$c \wedge m_x$	$001 \wedge 011$	51 41½	51 41½	51 35	
$\varepsilon \wedge \varepsilon$	$11\bar{2} \wedge 1\bar{1}\bar{2}$	48 19½	48 21		
$a \wedge \varepsilon$	$100 \wedge 11\bar{2}$	49 57	49 59		
$a \wedge o$	$100 \wedge 120$	51 45½	52 19		
$a \wedge Q$	$100 \wedge 122$	58 12	58 10		
$a \wedge U$	$100 \wedge 123$	62 58	62 54		
$a \wedge \beta$	$100 \wedge 121$	53 43½	53 41	53 42	
$c \wedge \beta$	$001 \wedge 121$	72 41	72 33		
$c \wedge Q$	$001 \wedge 122$	57 58½	57 59		
$c \wedge U$	$001 \wedge 123$	47 0½	46 54		

Probably the largest European crystals of datolite are those from Baveno, Italy. One of these described by Sella† is mentioned by Brush‡ as being 4·5 × 3·75 × 1·5 inches.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, Oct., 1892.

ART. XIII.—*A New Machine for Cutting and Grinding thin sections of Rocks and Minerals;* by GEORGE H. WILLIAMS.

A BRIEF description of a new machine for cutting and grinding rock sections in which electricity furnishes an economical and satisfactory motive power, may prove acceptable to the constantly increasing number of workers in mineralogy and petrography. This machine was devised for the petrographical laboratory of the Johns Hopkins University over a year ago, and since then it has been in more or less constant use. It has thoroughly established its reputation for accurate and rapid work, while experience has suggested some improvements on the original model.

* Pogg. Ann., 103, 116, 1858.
† Wien. Akad Berichte, xxix, 239.
‡ VIII Supp. Dana's Min. This Journ., May, 1860, vol. xxix, 2d series.

The accompanying cut of the machine (fig. 1) hardly needs any explanation. It is seen to consist of a substantial table, carrying in its lower part the electric batteries and motor

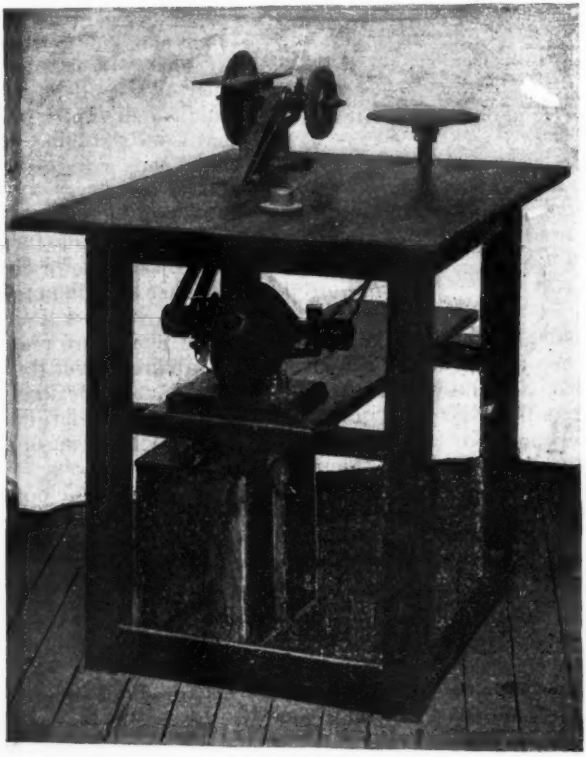


Fig. 1.

while upon its upper surface is placed the apparatus for grinding and sawing.

The table is approximately three and one-half feet square and two feet nine inches high. It is constructed with all of its appurtenances by the Donaldson-Macrae Electric Company of 215 N. Calvert St., Baltimore, whose storage batteries and electric motors are well known. The price of the machine complete is $130.00, consisting of the following parts:

1. Three two hundred ampère-hour storage batteries, 13 inches high, in portable rubber cases. These batteries stand

on a firmly constructed cross-piece from which they may be readily removed for recharging.

2. One one-eighth horse power electric motor of the Donaldson-Macrae pattern (fig. 2). This is fastened to a second cross-piece above the batteries and below the table surface. It is provided with two pulleys from which belts pass to the shafts on the table, which carry the grinding disks and diamond saw.

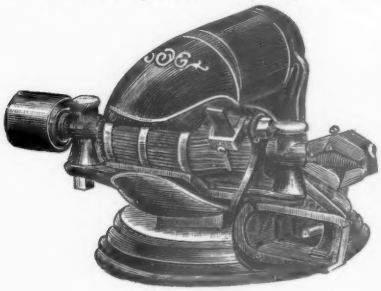


Fig. 2.

3. The grinding apparatus consists of two circular disks of solid copper, 9 inches in diameter and $\frac{3}{8}$ inch thick, which may be used alternately as different grades of emery are required. They are attached either by a screw or square socket to a vertical iron spindle which revolves smoothly in a conical bearing. The grinding disk is surrounded when in use by a large cylindrical pan of tin (not shown in the cut) which has an opening in its center to allow of the passage of the spindle.

4. The sawing apparatus consists of a horizontal countershaft, placed on a different part of the table from the grinding disk, and connected with the motor by a separate belt. It carries at one end a vertical wheel of solid emery, and at the other an attachment, level-table and guide for the diamond-saw.* A small water-can and spout (not shown in the cut) is suspended over the level-table to keep the edge of the saw wet when it is in use.

Under some circumstances it may be found advantageous to obtain electricity for this motor by a direct wire from an electric light or power company. Considerable inquiry has shown, however, that in Baltimore the storage batteries are more convenient, safe and economical. A single charging lasts the needs of a laboratory of ten students for a month. The batteries are removed by the electric company and returned with little or no delay at a cost of $3.75 for recharging.

Petrographical Laboratory,
Johns Hopkins University, Dec. 10, 1892.

* Admirable saws, circular tin disks 8 inches in diameter with one inch center aperture whose edge is provided with diamond dust secured by cement, may be had of Wm. Kerr, No. 292 Westminster St., Providence, R. I., for $12.00 per half dozen.

ART. XIV.—*Stannite and some of its Alteration Products from the Black Hills, S. D.;* by WM. P. HEADDEN.

SEVERAL years ago Mr. Fred. J. Cross found at the Peerless Mine, which is located about one-half mile northeast of the Etta Mine post office, and was then being worked for mica, a piece of some mineral imbedded in the pellucid quartz of the locality which he did not recognize as having seen before either from this or any other locality in the Hills. This material which he kindly gave me forms the subject of this investigation. One piece was all that Mr. Cross found at the time and, though he has subsequently sought for it diligently, he has been unable to find more of it, and I have been entirely unsuccessful in my search for it; therefore the description of the occurrence of this mineral in the Black Hills must be confined to the description of this one specimen with such exception as will be mentioned hereafter.

The exterior of the mass is earthy in texture and from dirty green to brownish yellow in color. The texture and color change rapidly the former becoming in the interior firm, almost massive, with uneven to subconchoidal fracture, while the color passes through a pure copper-green to greenish black. The appearance of the mass leaves no doubt but that it is what remains of an original mass now in an advanced stage of alteration. This is plain to the naked eye, but is best seen under a good pocket magnifier. The texture of the mass varies, even in those portions which are earthy, and where the alteration is most complete there are portions varying in size from mere points to particles as large as small shot which have a vitreous luster, a green color, and an uneven fracture which is rather difficult to observe. A closer study of these spots shows that they, like the mass itself, are filled with seams and are only remnants of an unrecognized decomposition product. While these particles are readily distinguishable from the enveloping mass, they are so permeated by seams filled with other material, probably identical with the mass itself, that no mechanical separation of the two would be possible. The dull earthy substance becomes less abundant in the interior but is nowhere absent.

The portion having a copper-green color is similar to the lustrous spots of the other portion and the two are probably identical. The former like the latter is traversed by a fine network of seams whose centers are filled with a substance appearing to be almost white when viewed with a rather strong magnifier. This is particularly easily observed in the larger

seams; but this substance which is one of the end products of the alteration, an impure oxide of tin, can be traced as minute threads running through the mass in every direction even into its deeper portions where small portions of the original stannite still remain.

The meshes of this reticulation are sometimes filled with an apparently homogeneous mass of a varying green color and strong vitreous luster, but this is rather exceptional. The rule is that they are filled with material which varies macroscopically and probably chemically; as some of the patches are white while others are different shades of blue or green.

The firmer portion of the mass is really not uniform in color, green and grayish black portions being intimately mingled, producing a greenish black. The stannite frequently shows a bronzy tarnish which makes the mixed nature of the mass apparent. The luster of this mass on a fresh fracture surface is metallic, its streak and powder are green and it yields three products when treated with hydric chloride, i. e. a solution containing a large amount of tin and a residue made up of fragments of the remaining stannite and a yellowish white powder consisting of stannic oxide with a trace of iron.

The stannite is grayish black. It tarnishes blue and bronze. Hardness 4; Sp. gr. 4 534, streak black. The material used for analysis appeared to be quite pure and free from the accompanying alteration products, but both the quantity of the material and the size of the fragments forbade any further attempt to purify it by gentle rubbing or other means. The analysis yielded the following results:

		At. eq.
Sulphur	28·26	88·31
Tin	24 08	20·40
Copper	29·81	47·16
Iron	7·45	13·30
Zinc	8·71	13·40
Cadmium	0·33	0·20
Antimony	trace	
Insoluble	1·51	
	100·15	

If we assume the copper to be present as cuprous and the tin as stannic sulphide, and express the atomic equivalents in terms of sulphur, we obtain:

Sulphur	88·31	or	6·64	6·64	1
Tin	40·80		3·06		
Copper	23·58		1·77	6·83	1·02
Iron	13·30		1·00		
Zinc	13·40		1·02		
Cadmium	0·20				

The ratio of the sulphur required by the tin as stannic sulphide to the total sulphur is as 1 : 2·16 or 1 : 2 giving us the formula $2RS+SnS_2$ in which $R = Cu_{\frac{1}{4}}$, $Fe_{\frac{1}{4}}$, $Zn+Cd_{\frac{1}{4}}$, which agrees with the formula heretofore accepted for stannite except that a small portion of the zinc in this specimen has been replaced by cadmium.

I have been very explicit in describing the mass from which I obtained this portion of stannite for the reason that about four years ago I found a similar earthy material occurring in patches in the coarse-grained granite of the Etta Mine. I succeeded in obtaining small quantities of this material at various times and finally enough for an analysis. The quantity actually obtained was rather more than 0·5 grm.

Whether it occurs more abundantly at some point in the workings which I have failed to find, I cannot say, but I found it occurring very sparingly. The chief portion of all that I obtained on my various visits to the locality extending over a period of two years was found scattered in small bunches through a large piece of granite which had been removed from its place and carried some distance from the mine. The point at which I found it most abundant in place was in the face of an open cut on the northeast side of the hill together with cassiterite; they are intimately associated with a somewhat laminated feldspar. I have reason to believe that it was more abundant formerly than now, as I came into possession of a specimen taken from the mine, under its first management, which is much richer in this material than any specimen which I have myself been able to find or to subsequently obtain. The association of this material with the cassiterite is more intimate in this specimen than is usual; in only one instance have I seen it more so, namely in a piece of massive cassiterite which has a small depression partly filled with it inclosing fragments of stannite. This is interesting because the specimen was found at the point where this cut was opened, and establishes the identity of the Etta and Peerless material so far as their origin is concerned. An analysis of the best Etta material that I could obtain was made in 1889 and is given here for comparison with one of Peerless material which was made recently. The air-dried material had a dirty green color and gave, after deducting 9·84 per cent gangue:

				Atomic equivalents.			
H_2O	13·87	H	·0154	15·40	14·66	29·3	30
CuO	12·53	Cu	·1021	1·615	1·44	2·88	3
Fe_2O_3	8·94	Fe	·0626	1·119	1	2	2
SnO_2	64·33	Sn	·5061	4·289	3·83	7·66	8
SO_3	trace	O	·3105	19·400	17·38	34·76	35
Sb_2O_5	trace						
ZnO	trace		0·9967				
	99·67						

It is true that we can give an interpretation to the ratios obtained, but a simple and necessary relation between them is not evident. Still if we assume the iron present as xanthosiderite and the copper as cupric hydrate we obtain the following: $Fe_2O_3 2H_2O$, $3Cu(OH)_2$, $5Sn(OH)_4$, $3SnO_2$. This would demand but two more atoms of oxygen than we have really found and this slight violence to the ratios found may be justifiable on the ground that these ratios are only approximate.

The identification of a new mineral, cuprocassiterite, has recently been announced by Mr. Titus Ulke.* The material which served for this identification was also from the Etta Mine and according to his description from the same (?) point in the mine, as no work has been done at this locality for several years, no new openings have been made. Mr. Ulke does not give the detailed results of his analysis but states "Upon analysis 60 per cent Sn, 12 per cent Cu, and 8 per cent H_2O were found with traces of iron and silica." This when calculated into oxides in which form these constituents evidently existed in the material gives:

				At. equiv.	
SnO_2	76·27	Sn	60·00	5·08	5
CuO	15·04	Cu	12·00	1·94	2
H_2O	8·00	H	·888	8·88	9
		O	26·43	16·52	16
	99·31				

Mr. Ulke proposes $4SnO_2 + Cu_2Sn(OH)_6$ as the formula corresponding to this analysis. He notices the presence of iron and silica but as the calculated analysis falls less than seven-tenths of one per cent short of one hundred there could have been no considerable quantity of either of these present. This must be an accident, for as I have stated before, the probabilities are strongly in favor of the material serving for the respective analyses being from the same spot, again there can be no doubt but that this material is an alteration product derived from stannite and it is somewhat remarkable that the iron should be so completely removed while the copper and so much of the tin remains in the form of hydrate. The varying composition of this material is not only indicated by the difference in the quantity of iron present but also by the ratios of the anhydrous to the hydrous oxides. Mr. Ulkes gives 4 : 2, i. e. $4SnO_2 : \begin{cases} Cu_2(OH)_2 \\ Sn(OH)_4 \end{cases}$, while my analysis gives 3 : 9, i. e. $3SnO_2 : Fe_2O_3 2H_2O + 3Cu(OH)_2 + 5Sn(OH)_4$ in which the copper is considered as cupric instead of cuprous hydrate.

* Proceeding American Institute of Mining Engineers, meeting of Feb., 1892.

Having a larger quantity of similar but purer material from the Peerless I subjected a portion of it to analysis. The air-dried material loses 5·06 per cent when dried at 100° and the dried mass is so hygroscopic that it regained 4·35 per cent of its original weight when exposed to the atmosphere for forty-five minutes, and after eighteen hours its loss amounted to only a few tenths of a milligram.

This material can be scratched with the finger nail; absorbs water with avidity and adheres quite strongly to the tongue and has a clayey odor and taste. I found the sp. gr. for two portions of the material 3·312 and 3·374 respectively. Mr. Ulke reports specific gravity nearly 5. Analysis of material dried at 100°:

Loss upon ignition	8·20		
Fe_2O_3	11·85		
CuO	18·02		
SnO_2	46·07	= 84·65	= Soluble in HCl
ZnO, CdO	0·51		
SO_3	trace		
Sb_2O_5	trace		
Gangue	1·68	14·64	Insol. in HCl
SnO_2 (Fe trace)	12·96	= ———	
		99·29	

Computing the portion soluble in hydric chloride to 100, we obtain

				Atomic equivalents.			
H_2O	9·68	H	0108	108·	11		$11H_2O$
Fe_2O_3	13·98	Fe	0978	17·46	2		$2Fe_2O_3$
CuO	21·34	Cu	1704	26·96	3		$6CuO$
SnO_2	54·40	Sn	4279	35·41	3·5	2	
ZnO, CdO	·60	Zn	0048	·74			$7SnO_2$
	100·00	O	[2883]	180·10	18		

This gives no approximation to any simple and evident formula for the portion soluble in hydric chloride. The solution gave no reaction for ferrous oxide even after gentle boiling indicating the absence of any ferrous, stannous or other lower oxide which would reduce the ferric salt under these conditions, while the color of the mass and the bright blue coatings on the fracture planes in the quartz point to the absence of an anhydrous cupric oxide. That the stannic oxide insoluble in hydric chloride is present as such and ought not to be considered as a part of some other combination is indicated by the macroscopic properties already detailed and even more strongly by the deportment of the material in lumps when

treated with hydric chloride, which removes the green, vitreous portion leaving a smaller or larger portion of yellowish stannic oxide, which usually preserves in some degree the form of the original network and sometimes sufficiently well, to show it plainly. I could observe no evolution of carbon dioxide when the powdered mass, thoroughly wet with water, was treated with hydric chloride.

The San Antonio tin ore as described by Professor F. A. Genth of Philadelphia* suggests the same problem presented here, but much more involved. In this article he calls particular attention to the fact that a portion of the stannic oxide amounting to 3·86 per cent of the weight of the ore is soluble in hydric chloride and adds that "it is difficult to perceive in which form this tin existed," but adduces proof that it was not present as stannous oxide.

It may justly be urged that my analyses of the Etta and Peerless material are not comparable because they were made by different methods. This is true only in regard to some of the data given by them, it does not change the fact that the constituents are the same but present in varying proportions and it is also probable that no material change was produced by drying at 100° as the water lost and no more was regained. Until fuller and more satisfactory data can be acquired concerning several points relative to this substance it can scarcely be considered as more than a mixture containing one or more hydrated compounds of copper, iron and tin related to the stannates, respectively the metastannates, which are soluble in hydric chloride but for which we cannot at the present time establish a formula.

The almost complete removal of the sulphur, the green and blue stains which are without doubt largely but not wholly due to the copper, found both in the quartz of the Peerless and to a less extent in the feldspar of the Etta, suggest that some of these alteration products are soluble in water and that such salts may have furnished the solutions from which the stannic oxide forming the imitative forms described by Prof. Genth in the article referred to was deposited. This may also help to the explanation of the pseudomorphs of stannic oxide after feldspar, first observed in Cornwall by Mr. Richard Pearce now of Denver, Colo. It seems very probable that such solutions have been the source of the stannic oxide deposited in small irregular patches on some of the spodumene crystals found in the Etta Mine.

State School of Mines, Rapid City, S. D.

* Contribution to Mineralogy, No. XXXI, 1887. Read before American Philosophical Society, March 18th, 1887.

ART. XV.—*The Occurrence of Hematite and Martite Iron Ores in Mexico;* by ROBERT T. HILL.

THE iron ores of Mexico have been frequently mentioned, but the writer is aware of no attempt to define their position and origin. The admirable paper of Mr. John Birkinbine, the well-known mining engineer, has made known the chemical composition and extent of the famed iron mountain of Durango,* and Prof. B. Silliman has described the peculiar occurrence of martite at this locality.†

The writer has recently studied several deposits of similar iron ores in Mexico, and in August, 1892, gave special attention to the study of certain beds situated on the line of the Mexican International railway, near the city of Monclova, in the State of Coahuila. The mountain in which the ore occurs, like the iron mountain of Durango, is known as the Sierra de Mercado, and is one of the elongated, isolated masses characteristic of the Great Basin region of the United States, of which the so-called Mexican plateau is a geographic continuation, and is surrounded by the customary basin plains, or valleys, filled in by debris of the mountains.

In structure the mountain is composed of sub-vertical strata of a hard blue and gray limestone, very much resembling the familiar Paleozoic mountain limestones of the Appalachian region, but which, in fact, as will be shown is of Mesozoic age. Through this limestone, in a direction usually corresponding with the strike of its stratification are vast masses of eruptive diorite, which simulate the limestone in color. Inasmuch as this diorite includes large fragments of the limestone in its substance there can be no doubt of its later origin.

The talus which imbeds the base of the mountain, and is widely distributed over the plain, is composed principally of limestone cobble, with a large admixture of rounded lumps of iron ore, black upon the surface, strongly resembling magnetite, but which reveal a lustrous (specular) surface structure upon fracture, and give the streak of hematite. This iron ore is so abundant in the talus that it suggests the fact that the beds from which it was originally derived have long been exposed to denudation.

In ascending one of the numerous lateral cañons at the south end of the mountain, many alternations of the limestone

* "The Cerro de Mercado (Iron Mountain) at Durango, Mexico, by John Birkinbine," Trans. of the Am. Inst. of Mining Engineers, 1884, pp. 1–19.

† "Martite of the Cerro Mercado, or Iron Mountain of Durango, and Certain Other Ores of Durango, by B. Silliman, this Journal, November, 1882.

and diorite are crossed, all of which strike in the direction of the axial trend of the mountain, with slight local sinuosities. At an elevation of about 1000 feet above the railway which skirts the base of the mountain, and nearly at the summit, the original source of the iron debris of the plain is found in large masses, or pseudo-veins, of ore, the bodies of which occur in a line corresponding with the strike of the limestone diorite contacts, and are principally exposed at the crests of the ridges dividing the lateral cañons. The ore bodies resemble fragments of a vertical vein, but apparently have no direct continuation. They occur along the line of contact between the upper limestone and the diorite, but some of the masses are entirely embedded in the limestone and others in the diorite, while several present a wall of each. The bodies could not be described as lenses, as are the masses of specular ore in either Algonkian or Archæan schist in Llano county, Texas, nor are they true beds, but apparently formed by the replacement of the limestone at the limestone-diorite contact, or replacement of the masses of limestone included in the diorite. The principal outcrops, seen along a north and south line of six miles, were as follows, beginning at the south end of the mountain:

1. The first lateral ridge projecting from the east side of the north end of the mountain is crossed by the vein or bed which upon one side reveals a cross section of 30 feet and an exposure of 250 feet parallel to the mountain crest north and south. 2. On the opposite side of the ridge apparently the same bed reappears with a vertical exposure of 50 feet. 3. In the same line of outcrop is a third exposure of apparently the same mass as No. 1. 4. Northward are two outcrops with areal exposures of 65×32 feet and 150×30 feet respectively. 5. One-half mile north of the above is another outcrop of the ore with a surface area of 30×240 feet. 6 One quarter of a mile northward is the mine known as La Paloma which has been somewhat developed; it has an areal exposure of 45×200 feet and a vertical face of 50 feet. 7. Still northward is an outcrop resembling No. 2 in quantity exposed. 8. Two miles north and nearest to Monclova is the last outcrop visited; it has a vertical exposure of 150 feet and a width of 30 feet at the top which rapidly diminishes downward.

All of these masses, from their uniform width and continuity of strike are apparently genetically connected continuously along a structural parting between the diorite and limestone.

The ore presents peculiar mineralogical conditions. Where the interior of the vein is exposed by blasting its mass consists of a bright lustrous (specular) hematite. This would not

be inferred from surface examination, however, for everywhere the mass has the exterior appearance of black magnetite and has been mistaken for this ore by many observers. Close examination of the surface shows it studded with minute granules and the octahedral crystals of martite—a hematitic pseudomorph after magnetite—resembling similar phenomena with the ores of Durango and other Mexican localities described by Prof. B. Silliman.* Of the Durango ores Prof. Silliman said:

"At first sight the octahedral crystals of various sizes suggested only magnetite, but the magnet failed to attract the ore while the streak immediately indicated hematite."

Mr. Birkinbine also notes the resemblance of the Durango hematite to magnetite; the writer was obliged to make the magnet tests before he was satisfied that the substance was not magnetite. In view of these facts it is necessary to be cautious about accepting the determinations of magnetite made by casual observers in other localities. In most of the outcrops only the hematite and martite could be seen, but in several outcrops, especially the one nearest Monclova, about a foot of limonite could be seen against the hanging wall of the limestone. Prof. Persifor Frazer has mentioned the occurrence of pyrite in the Paloma opening, and says:† "There is the clearest evidence that the iron ore is an alteration product of pyrite, but so complete has been the alteration that a few inches above the line of demarcation between the sulphide and the oxide hardly a trace of the sulphur remains." The writer must confess that after having examined many of these iron masses, he has never seen a trace of the pyrite beds above alluded to.

In chemical composition the ore shows great resemblance to many other localities in Mexico, especially those given by Mr. Birkinbine and Prof. Silliman, as shown by comparison with the following analyses of Paloma made by Mr. Davenport Fisher of Milwaukee, from eighty pure specimens collected by Mr. H. M. Wakefield of the same city:

Iron	64·83	Oxide	92·61
Silica			2·98
Phosphorus ...	·018		·04
Alumina			4·35
			99·98

No sulphur, manganese, lime, magnesia or titanium were found.

* Martite of the Cerro de Mercado or Iron Mountain, Durango, Mexico, and certain other Ores of Sinaloa. this Journal, Nov., 1882.

† Certain silver and iron mines in the States of Coahuila and Nuevo Leon, New Mexico," Trans. Am. Inst. Mining Engineers, vol. xii, pp. 538–568.

Dr. Frazer "in order to test the value of this ore severely" took a sample across the face inclosed in the pit inclusive of a horse of limestone there visible, and some scattered masses of sandy material, which gave 53·80 per cent of metallic iron." He gives 0·61 to 4·5 of sulphur in the various analyses of this impure sampling.

It is not the purpose of this paper to advance an opinion of the origin of this ore, for the writer is unable to satisfy himself upon this subject, but the opinion of Prof. Frazer that they are altered pyrites is contrary to his observation. The limestone may be looked upon as the most probable source, however, for occurrences of smaller quantities of iron ore have been frequently reported at the contact of igneous and calcareous rocks, and ores of Jalisco are reported entirely surrounded by limestone. It is interesting to note that these masses always occur in the vicinity of eruptive intrusions into the limestone and in some cases are entirely embedded in it. In some of the adjacent Cretaceous limestones was found a small weathered ammonite encrusted with limonite, showing that the limestone contains iron ore and that it concentrates upon the surface. In the silver-bearing fissures and veins of the same limestone which the writer has examined in many parts of Mexico there is always a residuum of excessively ferruginous clay. In the unaltered limestones of the Comanche series in Texas, notably at Austin, there are many nodules of iron oxide, especially in the Washita beds (the horizon of the Monclova limestones) which are the result of alterations of balls of pyrites. Along the veins and faults of Barton creek are deposits of ferruginous clay derived from the apparently pure white chalky limestone. The fissure at the contact of the Comanche limestone and diorite in which these Mexican ores are deposited can readily be explained by the mountain stresses or chemical solution of the limestone. The diorite is cross or double jointed and the fissures are filling with limonite by hydrous deposition, as can be seen in every crevice. We learn that certain Norwegian geologists have thus explained the origin of iron deposits in that country, but it is not proposed to maintain that the Mexican ore bodies so originated, although Barcena the eminent Mexican geologist asserts that in the mineral district of Agostadero, in the State of Jalisco, one can see specular iron ore in process of formation in the feldspathic rocks, through the agency of percolating waters charged with the hydroxide of iron, and percolating into the fissures of the rock.*

* Tratado Geologica, etc., por Mariano Barcena; Edicion de la Secretaria de Fomento. Mexico, 1886, p. 90.

The most interesting fact is the unusual geological age of the ore, and its occurrence different from any of our own country, unless the ore at Van Horn, in Trans-Pecos Texas, a part of the same geological province, is similar.*

The principal specular ores of the United States are from the older Paleozoic and Archæan rocks, and as we proceed upward in the geological column they decrease in compactness and in luster. In fact the Mexican ores have a strong resemblance to those of the Superior district, and practical miners often speak of them as identical, a mistake which is further instigated by the Paleozoic aspect of the Mesozoic and Tertiary phenomena of the region. The diorite is called "granitico" by the natives, and is spoken of as granite by one of our prominent mining engineers.† The coal fields of the Sabinas, which extend to within thirty miles of the iron deposits have been often referred to as Carboniferous and Triassic‡ until their Laramie age was shown by Dr. C. A. White, in 1886. The massive Paleozoic-looking limestone is undoubtedly of Lower Cretaceous age, and contains the characteristic Terebratulas, Pectens, Limas, Aviculas, Monopleuras, Ammonites, Radiolites and Nerineas of the Comanche Series of Texas, and is the result of alteration of the same beds which have a chalky aspect in the non-mountainous portion of the latter state. This limestone was published as Silurian by Rock,§ and Frazer received conditional opinions from Prof. Angelo Heilprin and James Hall to the effect that it was probably of Carboniferous age.‖

The diorites, as shown by their intrusion through the Comanche limestone at the Sierra Mercado of Monclova, and through both the limestone and the Laramie beds in the Sierra Candella, are clearly of post-Cretaceous age. Mr. Whitman Cross, of the U. S. Geological Survey, has kindly studied these for me, and his mineralogical notes are appended. His remark that they strongly resemble certain post-Cretaceous eruptives in Colorado, is an important point. These diorites have a wide distribution over the Mexican plateau. It is very evi-

* The writer has seen masses of ore from Van Horn which resemble in mineralogical characters the Mexican ore.

† Dr. Frazer in the paper already cited, speaks of the diorite both of the Sierra de Mercado of Monclova and of the Carrissal and Villadama regions as "granite."

‡ Mr. W. H. Adams, in an otherwise excellent paper refers these coal fields to the Trias. See "Coal in Mexico: Santa Rosa District." Trans. Am. Inst. Mining Engineers, vol. iii, pp. 25–28. 1874.

§ Report on Examinations of the San Rafael Mining Company's Mines, by Adolphe Rock, Mobile, 1876.

‖ Both of these geologists stated that the paleontologic evidence furnished them by Prof. Frazer was insufficient to accurately determine the age of these limestones, and that their opinions were largely based upon their lithologic characters. See Dr. Frazer's paper, previously cited.

dent that the iron ores are of later age than the rocks in which they occur, and this period was probably near the Eocene, for many of the basin plains of Mexico similar to that of Monclova in which the debris of the iron ore is found, contain the Loup Fork and Equus vertebrate Tertiary faunas of Cope.

Having now described the geology of the Monclova ores as a typical locality of these peculiar Tertiary Mexican martite hematites, it may be well to examine the distribution of similar occurrences in Mexico. The local geology of Monclova, is typical of the geology of the whole of the Mexican mountainous (plateau) region, which may be briefly described as remnants of numerous folds of Comanche limestone (also the Laramie sands and clays in the northeast), frequently broken by protrusions of eruptive material, and separated by basin valleys, largely covered by the debris of the mountains. Only along the southern border of the plateau and in the extreme northwestern States are the older rocks of the Archæan or Paleozoic exposed.* All the following localities of iron ore are from this region of Cretaceous limestone and Tertiary eruptives, with the possible exception of Prof. Silliman's localities in Sinaloa, where Carboniferous limestones also occur as well as the Cretaceous.

The Sierra Candella Beds.—Seven miles west of the town of Salomon de Botia, and about sixty miles east of Monclova near the Mexican National railway, the writer examined several large deposits of ore similar in composition and occurrence to that of Sierra de Mercado at Monclova. Although an entirely different group of mountains from those of Monclova, the Sierra Candella consists of the same Comanche limestone, and dioritic eruptives. The Laramie beds however occur as foot hills on both sides of the Sierra Candella.

The Sierra de Mercado of Durango.—About three hundred miles southwest of the Sierra de Mercado of Monclova is the Sierra de Mercado of Durango, commonly known as the iron mountain of Durango. It was from this locality that the occurrence of martite was first noted by Prof. Silliman. The mountain has been well described by Mr. John Birkinbine† who says, "The hill is nearly a mile long and a third of a mile wide, and from four to six hundred feet high." . . . . "I am inclined to believe that the Cerro de Mercado is formed of one or more immense lenses of specular ore, standing vertically, the fragments of which have for ages been thrown down to

* The writer has reserved for a future paper the discussion of the general geology of the region.

† Loc. cit.

form the slopes of the mountain as a talus." . . . . "I am free to say that after having visited the iron mines of the United States, I have found nothing as yet to compare as to quantity in sight with the Cerro de Mercado of Durango." Unfortunately there has been no attempt at a description of the geology of this mass except that given by Wiedner,* whose allegation that it is the cone of an ancient volcano is erroneous, as can be seen by referring to Mr. Birkinbine's excellent picture of the mountain which was reproduced in this Journal.† The only mention throwing light upon the nature of the country rock is that given by Prof. Silliman, who says:‡ "From samples of the country rock which I find in Mr. North's collection the (enclosing) walls are of purple porphyry; which would indicate that the Durango mass is accompanied by eruptive rocks as in the other cases mentioned." Inasmuch as the iron has been smelted for many years in primitive furnaces, requiring fluxes without rail transportation, it is very probable that the Comanche limestone (the chief sedimentary rock of Durango) cannot be very far distant from the mines. Prof. Silliman's description of the martite and hematite ores of Durango makes them appear to coincide so perfectly with those of Monclova, that it is difficult to believe otherwise than that the two deposits are geologically related.

Jalisco.—Iron has been smelted for many years in this State, in the vicinity of Tula, southwest of Guadalajara. The deposits have been briefly described by Mr. J. P. Carson.§ According to this writer, the ore occurs in four distinct districts. The Amole mine in the district of Tula is bounded on one side by "a trap dyke" and on the other by a shaly disjointed sand rock. In the other districts the ore occurs under conditions similar to those of Monclova. In the district of Chiquilistlan, Mr. Carson says "the formation is limestone—probably Tertiary—greatly upheaved by volcanic action and penetrated in various directions by volcanic dykes." In the Tecotes mine the "vein is what is termed segregated, occupying a space between parallel seams of limestone." The Los Animas mine, which he says can be traced for a distance of over one thousand feet is also in a segregated vein of limestone." These limestones, instead of being Tertiary, as conditionally stated by Mr. Carson, are very probably the Comanche limestones of the Cretaceous, for Barcena describes them as Cretaceous and gives a list of fossils which are char-

* Quoted by Mr. Birkinbine.

† See Prof. Silliman's paper previously cited. ‡ Loc. cit.

§ Iron Manufacture in Mexico. by J. P. Carson; Trans. Am. Inst. Mining Engineers, vol. vi, 1887–88, pp. 399–415.

acteristic Comanche species. The latter author also publishes a map of Jalisco, in which the eruptive rocks in the vicinity of these mines are for the most part called dioritic.*

Sinaloa.—Prof. Silliman, in the valuable paper referred to, describes several occurrences of martite in Sinaloa. Almost nothing is known of the general geology of this State, but from the descriptions given of the ores at Tepuche, Bescuino and Cosolu, the conditions seem similar to those of Durango and Monclova. He says that the iron of Tepuche "occurs in a porphyry resembling that of the Sierra de Mercado" (of Durango), and that those of Cosolu are surrounded by calcareous rocks. The localities also yield magnetite.

Hidalgo, Mihoacan, Queretaro, Zacatecas and San Luis.—There are many references to ores in these States in the Mexican geological literature, which lead to the inference that they are of the same character as those we have described. In Queretaro, Barcena mentions the occurrence of a hematite which he "believes is contemporaneous with the porphyry." He also describes the occurrence of hematite associated with tin in a Tertiary porphyry in the Meza de los Caballos of Zacatecas. In Hidalgo he says there are large beds of hematite, mixed with magnetite, in the post-Cretaceous formations. He refers to many other localities in the States of Jalisca, Durango and Mihoacan, and says that these ores constitute the chief deposits of iron in the republic.† Virlet‡ mentions the occurrence of iron ore at the contact of limestone and diorite in the eastern Sierra Madres, in the State of San Luis.

Guerrero.—One of the most interesting descriptions of iron ore in Mexico is that given by Manross in this Journal for May, 1865. He mentions eight localities of the occurrence of iron ore in Guerrero, which, with the exception of his age determinations, greatly resemble the Monclova and Durango deposits. "The first of these is situated at a distance of four miles from Mescala. It is a vein twenty five feet wide and nearly vertical, and consists of solid magnetite ore." Another is "three hundred feet high, half a mile long and fully one-third of its bulk is pure magnetic ore." It "contains a bed of limestone at its summit." Another is four hundred yards long and one hundred yards wide. The unfortunate death of this young student renders it impossible to ascertain further data from him concerning the ores. At the time he wrote his

* Ensayo Estadistico del Estado de Jalisco, etc, por Mariano Barcena. Mexico. 1891.

† These notes are taken from various observations following the mineral descriptions in Barcena's "Tratado," already quoted. Other notes on iron are found in his various statistical essays on the separate States of Mexico.

‡ Coup d'œil général de la topographie et la géologie du Mexique, etc., par M. Virlet d'Aoust, Bull. Soc. Géologique de France. 1866.

descriptions, however, the massive Cretaceous limestones of Mexico were generally supposed to be of Paleozoic age, and the difficulties of liability to mistake the superficial martite of the hematite deposits for magnetite has already been cited in the experiences of Mr. Birkinbine, Prof. Silliman and the writer. Mr. Manross himself remarks that "what is still lacking is the evidence of the fossils" to prove that a coal vegetation has once existed in these latitudes." Señor Castillo, upon his geological map of Mexico gives no sedimentaries of Paleozoic age in this region, the only ones indicated being Cretaceous. He does give metamorphic and primitive rocks however and eruptives, and the Archæan which has been reported east of this State may extend into it.

In conclusion it may be said that the occurrence of such large masses of hematite in rocks of Cretaceous and Tertiary age is of great interest, and that the Mexican ores of this character, accompanied by martite have a wide occurrence in that republic, which will be an important factor in the future iron supply of the world. Prof. Frazer remarks that it would pay to import these ores for mixture, as Cuban ores are now imported. Ten years ago Prof. Silliman said of the Durango iron: "The enormous mass of valuable iron ore, thanks to the near approach of the railway of Mexico, is now likely to become of commercial importance." Exactly ten years from the month of publication of his article the Mexican International railway celebrated the completion of its line to the foot of the Durango iron mountain, connecting it by rail with the coal fields of the Sabinas, and the prophecies of Profs. Silliman and Birkinbine are on the eve of fulfillment.

The accompanying note by Mr. Whitman Cross upon the eruptive rocks of Coahuila are of interest in connection with the discussion of the iron deposits. The general geology of the region will be given in another paper.

Igneous rocks from the Coal and Iron regions of Coahuila and Nueva Leon, Mexico, collected by R. T. Hill; by WHITMAN CROSS.

1. *Basalt overlying Laramie coal fields.*—Mesa, 6 miles east of Santa Rosa de Musquez. A rock of simple normal constitution. *Olivine* crystals in various stages of decomposition are the only porphyritical constituent. Groundmass of small plagioclase staves and augite grains. There seems to be no

magnetite in usual form, but a black substance occurs in angular spaces between other minerals. This seems to be secondary. There is no glass base.

Composite quartz grains are surrounded by zones of augite as described by Iddings, Diller and others.

2. *Diorite from Sierra Mercado of Monclova.*—A quartzose hornblende-diorite. The rock is a mass of small stout plagioclase crystals and irregular hornblende prisms pressed close together with quartz as the chief cementing substance though there is probably a little orthoclase, and plagioclase also, as interstitial matter. This rock is quite different mineralogically from the diorite of Sierra Candella.

3. *Hornblende-porphyrite.*—The rock has hornblende and plagioclase phenocrysts in a prominent finely granular cryptocrystalline groundmass. It might be a porphyritic equivalent of diorite No. 2.

4. *Vein matter in diorite.*—A fine-grained mixture of orthoclase and quartz. Has no microcline or micropegmatite, or plagioclase. Is like vein matter commonly found in granite or diorite masses.

5. *Hornblende-porphyrite.*—Hornblende and plagioclase are the main phenocrysts and the groundmass is unevenly granular, orthoclase being the chief substance. There is very little if any quartz.

7. *Augite-diorite.*—Sierra Candella. This rock is chiefly made up of a dark green augite in imperfect prisms, plagioclase in tablets with very strongly marked zonal structure, and orthoclase, the latter surrounding the plagioclase in a regular growth. There is some biotite, occasionally appearing in blades nearly an inch long; hornblende is intergrown with augite in the outer zone of some crystals. It is never very intricately intergrown with augite. Quartz occurs in a few small grains, and magnetite, titanite, apatite and zircon, are accessory as usual.

This rock differs in composition from the other diorite in the presence of augite in place of hornblende, and in the abundance of orthoclase.

These diorites are deep-seated eruptives similar in composition to several Colorado occurrences which were erupted in some period not long after the Cretaceous, as they cut upper Cretaceous strata, but are affected by orographic movements of early Tertiary time.

The porphyrites are no doubt equivalent to the diorites, but from smaller masses and perhaps consolidated nearer the surface.

ART. XVI. — *On the Cæsium- and the Potassium-Lead Halides;* by H. L. WELLS.

As a continuation of the work on double halides, in this laboratory,* a study of the cæsium-lead salts has been undertaken by Messrs. G. F. Campbell, P. T. Walden and A. P. Wheeler. These gentlemen have carried out the investigation with much enthusiasm and skill, and I take pleasure in expressing my obligations to them. They have established the following salts:

Cs_4PbCl_6	Cs_4PbBr_6	------
$CsPbCl_3$	$CsPbBr_3$†	$CsPbI_3$
$CsPb_2Cl_5$	$CsPb_2Br_5$	------

These results showed the existence of three types of lead double halides, the first of which fails to conform with Remsen's law‡ concerning the composition of this class of bodies.

Since the recent investigations of Remsen and Herty§ had indicated the existence of only a single type of potassium-lead halides, a new investigation of these seemed desirable, especially since these authors had denied the existence of Boullay's salt,‖ K_4PbI_6, which corresponds to one type of the new cæsium compounds. I have, therefore, undertaken this work and, as a result, have obtained the following salts:

--------	$K_2PbBr_4 . H_2O$	--------
$3KPbCl_3 . H_2O$	$3KPbBr_3 . H_2O$ / $KPbBr_3 . H_2O$	$KPbI_3 . 2H_2O$
KPb_2Cl_5	KPb_2Br_5	--------

It is to be noticed that neither Boullay's iodide nor any corresponding chloride or bromide was obtained among these salts. On the other hand, the compound $K_2PbBr_4 . H_2O$ belongs to a type which had not been discovered among the cæsium salts, so that, taking the cæsium and potassium series together, the existence of four types of double lead halides is shown.

The compound K_2PbBr_4, the anhydrous form of the salt just mentioned, is ascribed to Löwig,¶ but although iodides belonging to the same type have been described, $K_2PbI_4 . 4H_2O$ by Ditte** and $K_2PbI_4 . 2H_2O$ by Berthelot,†† neither Remsen

* This Journal, III, xliv, 155, 157 and 221.
† This compound is dimorphous. ‡ Am. Chem. Jour., xi, 296.
§ Am. Chem. Jour., xiv, 107. ‖ Ann. Chim. Phys., II, xxxiv, 336 (1827).
¶ Gmelin's "Handbook," English Ed. of 1850, v, 162.
** Ann. Chim. Phys., V, xxiv, 226, 1881.
†† Ann. Chim. Phys., V, xxix, 289, 1883.

and Herty nor I have been able to prepare them. Although these iodides and Boullay's salt, K_4PbI_6, belong to types which certainly exist, I am inclined to believe, with Remsen and Herty, that the products which gave these formulæ were mixtures of $KPbI_3 . 2H_2O$ and KI. The absence of more than one iodide in the cæsium series strengthens this view.

Remsen and Herty obtained the salt $KPbI_3 . 2H_2O$ under wide variations of conditions and I have confirmed their results. This salt was first obtained by Boullay* and analyzed by him, after drying over lime, in an anhydrous condition. Berthelot† has described a compound, $K_4Pb_3I_{10} . 6H_2O$, which differs but slightly in required composition from the above salt, and his description of it agrees with that compound. There is no doubt, therefore, that he really obtained the compound $KPbI_3 . 2H_2O$ and that his analyzed products were slightly contaminated with potassium iodide. Berthelot attributes $K_4Pb_3I_{10}$ to Boullay. The latter chemist, however, derived the correct formula, equivalent to $KPbI_3$, from his analysis, but since this did not agree closely with theory, Gmelin‡ derived the above-mentioned formula from it, and this has been frequently copied in more recent chemical literature.

Schreinemakers,§ in connection with an investigation on the equilibrium of the double salt of iodide of lead and potassium in aqueous solution, has assumed that Ditte's formula was correct as far as the composition of the anhydrous compound was concerned. By making a number of water determinations, without determining lead, potassium or iodine, he arrived at the formula $K_2PbI_4 . 2\frac{1}{2}H_2O$. It is absolutely certain, from his description of the salt and his method of preparing it, that he had the compound $KPbI_3 . 2H_2O$; moreover, his water determinations, 5·52, 5·72, 5·89, 5·93 and 5·16 per cent, agree satisfactorily with the calculated amount, 5·90, for this salt.

Remsen and Herty made only a single chloride, and likewise only one bromide. The other chloride, and the two bromides belonging to other types crystallize beautifully and are as easily made as the salts which they prepared, and it is a strange coincidence that the latter happened to correspond in type to the iodide which they had obtained. I have confirmed the composition of their bromide, $KPbBr_3 . H_2O$, but their chloride, to which they gave the formula $KPbCl_3$ is evidently identical with the compound which I have found to be undoubtedly hydrous, $3KPbCl_3 . H_2O$.

* Ann. Chim. Phys., II. xxxiv, 336, 1827.
† Ann. Chim. Phys., V, xxix, 289, 1883.
‡ "Handbook." English ed., 1850, v, 161.
§ Zeitschr. Physikal. Chem., ix, 57, 1892.

Löwig, as already mentioned, has described the compound K_2PbBr_4. I have been unable to find his original article, but from the fact that I have not obtained an anhydrous form of this compound, I believe that he overlooked the water of crystallization or dehydrated the salt before analyzing it.

A bromide, $K_2Pb_2Br_6$ is mentioned by Berthelot.* He does not give any analysis or description of it, and I am convinced from my own experiments that he obtained a mixture of $KPbBr_3 . \frac{1}{3}H_2O$ and KPb_2Br_5.

Strohecker† states that he produced three different chlorides of potassium and lead by mixing potassium chloride and lead nitrate solutions. It is remarkable, considering the abundance and cheapness of the materials and the ease with which large quantities of the double salts can be made, that he did not obtain them in sufficient quantities for exact analyses. Since I have succeeded in making only two double chlorides, I believe that one of Strohecker's salts, which he describes as feathery, was simply lead chloride.

The results of previous investigators may be summed up by saying that it is probable that no potassium-lead halides have been correctly described, if water of crystallization is taken into consideration, except two of Remsen and Herty's salts, $KPbBr_3 . H_2O$ and $KPbI_3 . 2H_2O$.

Method of Preparation.

Both the cæsium and potassium salts have been investigated, in every case, by making hot, aqueous solutions of the component halides and cooling to crystallization. Some previous investigators had used solutions of lead nitrate and an alkaline halide for the purpose, but their example has not been followed, because it was not believed that the presence of an alkaline nitrate would in any way facilitate the operation, and it was feared that it might incur contamination in some cases. The conditions were gradually varied from a point where the alkaline halide crystallized out, to a point where the lead halide was deposited uncombined, and the experiments were so carefully carried out and so frequently repeated that it seems scarcely possible that any double salt was overlooked.

The salts have been made on a rather large scale. In the case of the cæsium compounds, the rarity of the material made it necessary to perform the separate experiments with only about 50 or 75 grams of a cæsium halide, but in making the potassium salts 400 or 500 grams of a potassium halide were frequently used.

* Ann. Chim. Phys., V. xxix, 289, 1883.
† Jahresbericht, 1869, 282.

Solutions which were neutral or slightly acid were generally used. The effect of the presence of a large amount of free acid, hydrochloric, hydrobromic or hydroiodic, as the case required, was also carefully studied, but these had no apparent effect upon the results.

Very large crops of the potassium salts were sometimes formed, so that the homogeneity of the mass was doubtful. In such cases the greater part of the crop was removed and satisfactory crystals were obtained by dissolving the remainder in the mother-liquor by the aid of heat and cooling.

The cæsium material used was wholly from the pollucite of Hebron, Maine.* The salts were carefully purified for this investigation. Godeffroy's method† was found to be very satisfactory for the purpose of separating cæsium from the sodium and potassium which accompany it in the mineral.

Kahlbaum's potassium chloride, bromide and iodide were usually used for making the potassium salts, but for a few experiments the ordinary medicinal potassium bromide was substituted. Since some of the analyses of the double bromides show an excess over 100 per cent, it is suspected that the salts contained a little chlorine. Calculation shows that one per cent of chlorine replacing bromine would cause an excess of 0·71 per cent if the chlorine was weighed as silver chloride and calculated as bromine.

The lead halides which were used were prepared by ourselves from reliable materials.

General Properties.

The lead double halides are all decomposed by water, and the presence of a large excess of the alkaline halide is necessary for the formation of all the compounds to be described except $CsPb_2Cl_5$ and $CsPb_2Br_5$, which are almost stable with water. The concentration of the alkaline halide solution evidently determines, in the cases of the chlorides and bromides, the type of salt produced. Since the simple cæsium halides are much more soluble than those of potassium, it is possible to use them in much more concentrated solutions, and the salts Cs_4PbCl_6 and Cs_4PbBr_6 are readily obtained. In the case of potassium bromide the solution becomes saturated with the simple salt by concentration just beyond the point where $K_2PbBr_4 . H_2O$ is obtained, and with potassium chloride, which is less soluble than the bromide, the limit is reached at the compound $3KPbCl_3 . H_2O$. The apparent existence of only a single double iodide, both with cæsium and potassium, is remarkable since cæsium iodide is

* This Journal, III, xli, 213. † Berichte d. Chem. Ges., vii, 375.

very soluble and potassium iodide is much more soluble than the bromide and chloride.

On account of their decomposition by water, no determinations of the solubility of the double halides have been made, but it was noticed that the cæsium compounds were much less soluble in the saline solutions than the corresponding potassium salts. This relation corresponds with the observation of Godeffroy,* that while the simple salts increase in solubility from potassium to cæsium, the double and complicated salts show a decrease in this direction.

All the chlorides and bromides described in this article are colorless, or in one case nearly so, except two cæsium salts, $CsPbCl_3$ and one modification of $CsPbBr_3$. The first of these is pale yellow and the other bright orange. These colors are very remarkable since the simple halides from which they are made are all colorless. I have previously observed a similar case, where a colored double halide was formed from two colorless halides, in the compound $CsHgBr_3$.† Both double iodides are yellow, the hydrous potassium salt being the paler of the two.

Analytical Methods.

Great care was used in selecting homogeneous material for analysis. The crystals were dried as rapidly and thoroughly as possible by pressing them between smooth filter-papers, and where the substance did not lose its luster by the operation, it was then exposed to the air for several hours.

Water was determined by collecting and weighing it in a calcium-chloride tube, the substance being ignited in a combustion-tube, behind a layer of dry sodium carbonate, in a current of dry air. The water lost over sulphuric acid or at certain temperatures was determined by the usual methods.

Lead was determined in two ways. With all the cæsium salts the substance was dissolved in hot water (an easy operation with all these salts, but impracticable in the case of some of the potassium compounds), and all except a trace of lead was precipitated by ammonium carbonate in presence of ammonium hydroxide. The precipitate of lead carbonate was removed by filtration and the remaining trace of lead was precipitated by passing hydrogen sulphide into the alkaline solution. The lead sulphide was collected and ignited by itself in a porcelain crucible. The amount of this was so small that it was evident that no appreciable error would arise from any lead sulphate that the ignited residue might contain, so that the main precipitate of lead carbonate was ignited in the same

* Berichte d. Chem. Ges., ix, 1365. † This Journal, III, xliv, 227.

crucible and the whole was weighed and calculated as lead oxide. A different method was selected for the determination of lead in the potassium compounds, for the reason that some of them could not be readily dissolved in hot water, and it was found to be more convenient and expeditious than the other. About one gram of substance was dissolved in about 10^{cc} nitric acid (sp. gr. 1·20), about 2^{cc} concentrated sulphuric acid, previously diluted with water were then added and the nitric acid was removed by evaporation. After diluting with about 25^{cc} of water and cooling, the lead sulphate was collected in a Gooch crucible, washed with very dilute sulphuric acid, ignited and weighed.

In order to determine cæsium, the alkaline solution from which the lead had been removed was concentrated until the ammonium carbonate, hydroxide and sulphide had been nearly or quite removed, a small excess of sulphuric acid was added, and, after evaporation and ignition, normal cæsium sulphate was obtained by igniting in a current of air containing ammonia and this was weighed.

The filtrates from the lead sulphate did not contain an appreciable amount of lead. Normal potassium sulphate was obtained from these solutions by evaporating, igniting and heating in an ammoniacal atmosphere.

The halogens were determined as silver halides. Where the substance could be completely dissolved in hot water, an excess of silver nitrate was added to the hot solution and it was afterwards acidified with nitric acid. When it happened that the lead halide remained partly undissolved, the nitric acid was not added until this had been completely decomposed by long digestion on the water-bath with an excess of silver nitrate. The precipitates were collected and weighed in Gooch crucibles.

The Cæsium-Lead Chlorides; by G. F. Campbell.

Cs_4PbCl_6.—When lead chloride is dissolved, by the aid of heat, in a solution of cæsium chloride which is so concentrated as to be nearly saturated when cold, this salt is deposited on cooling in the form of brilliant, white rhombohedrons. Crystals having a diameter of 2 or 3^{mm} were sometimes obtained. Two entirely separate crops were analyzed, both of which were undoubtedly free from other compounds.

	Found.		Calculated for Cs_4PbCl_6.
Cæsium	55·60	56·03	55·90
Lead	----	21·63	21·75
Chlorine	21·97	22·23	22·35
		99·89	100·00

$CsPbCl_3$.—On gradually diluting the concentrated solution of cæsium chloride, such as was used in making the previous salt, and dissolving lead chloride in it as before, a point is soon reached where short prismatic crystals of small size and of a pale yellow color are deposited on cooling. Three different crops of apparently pure crystals were analyzed.

	Found.			Calculated for $CsPbCl_3$.
Cæsium ...	31·33	30·54	30·13	29·79
Lead	44·99	45·28	46·29	46·36
Chlorine...	23·85	23·75	23·71	23·85
	100·17	99·57	100·13	100·00

$CsPb_2Cl_5$.—Experiments with still more dilute solutions, carried out in a similar manner, gave, under wide variations of conditions, this salt in the form of thin white plates which were often several millimeters in diameter. These plates presented marked variations in habit, which were apparently due to changes in the conditions under which they were made. In two crops, of which A and B are the analyses, the plates were uniformly rhomboidal in form. Two other crops, C and D, were made up of lengthened plates, so twinned as to form feathery aggregates. In another crop, E, made from a more dilute solution than the others, the plates were apparently square.

	Found.					Calculated for $CsPb_2Cl_5$.
	A.	B.	C.	D.	E.	
Cæsium ..	19·99	18·44	18·27	....	18·45	18·36
Lead	57·14	57·16	57·06	56·98	57·08	57·16
Chlorine .	....	24·47	....	24·52	24·35	24·48
		100·07			99·88	100·00

The three different habits in which this salt crystallizes are so distinct in appearance that, before the samples were analyzed, it was supposed that they were separate compounds. It appears probable that the compound is at least dimorphous.

The Cæsium-Lead Bromides; by P. T. Walden.

Cs_4PbBr_6.—This salt is produced, in concentrated solutions, similarly to the corresponding chloride. Like the latter salt it forms white rhombohedrons. The crystals were usually not over 1 or 2^{mm} in diameter. Two separate crops were prepared and analyzed.

	Found.		Calculated for Cs_4PbBr_6.
Cæsium	43·61	43·42	43·64
Lead	16·83	16·83	16·98
Bromine	39·24	39·33	39·38
	99·68	99·58	100·00

$CsPbBr_3$.—This compound is dimorphous. One modification forms small prisms of a bright orange color, the other is pure white and crystallizes in slender needles. The orange salt is obtained when lead bromide is dissolved in somewhat more dilute solutions of cæsium bromide than those required for the formation of Cs_4PbBr_6, and there is a narrow range of conditions where it crystallizes upon the latter salt. There is, therefore, no evidence of the existence of an intermediate compound, Cs_2PbBr_4, corresponding to one of the potassium-lead bromides. Whenever solid lead bromide is added to a concentrated solution of cæsium bromide, it instantly loses its white color and takes on that of the orange salt. The white needles are formed in solutions which are slightly more dilute than those required for the orange modification. The limits of the conditions, under which this white salt is formed, are very narrow and a great many trials were necessary before satisfactory crops were obtained. Two distinct samples of each salt were analyzed. The white needles were not absolutely free from the orange compound, but there is no doubt that they were sufficiently pure to show their composition accurately.

	Found.				Calculated for $CsPbBr_3$.
	Orange salt		White salt.		
Cæsium	23·19	23·13	23·02	22·49	22·93
Lead	35·69	35·39	35·24	35·88	35·69
Bromine	41·37	41·34	41·47	41·45	41·38
	100·25	99·86	99·73	99·82	100·00

On heating the white modification to about 140°, it gradually assumes the exact color of the orange salt, without changing its external form, and this color is permanent on cooling.

$CsPb_2Br_5$.—This salt is produced in solutions which are still more dilute than those from which the preceding compounds are obtained. It was first noticed at a volume of about 160^{cc} of a solution containing about 50^{g} of cæsium bromide. It continued to form, on further dilution and the addition of lead bromide, until the volume reached 1250^{cc}, when lead bromide began to be deposited. The conditions under which the salt is formed are, therefore, very wide. The

compound crystallizes in thin, white plates, which, like the corresponding chloride, present considerable differences in habit. Plates having a diameter of about 5^{mm} were sometimes obtained. Three separate crops of crystals were analyzed.

	Found.			Calculated for $CsPb_2Br_5$.
Cæsium	14·13	14·35	----	14·05
Lead	43·39	43·72	43·45	43·71
Bromine	42·23	42·21	----	42·24
	99·75	100·28		100·00

The Cæsium-Lead Iodide, and some Mixed Double-Halides; by A. P. Wheeler.

$CsPbI_3$.—Under a great variety of conditions this was the only double iodide that could be produced. The compound is but slightly soluble in hot cæsium iodide solutions, so that the crops obtained were always small. It forms very slender, rectangular prisms which are yellow in color. The following analyses were made on separate products:

	Found.		Calculated for $CsPbI_3$.
Cæsium	17·90	----	18·45
Lead	28·38	27·40	28·71
Iodine	52·83	52·57	52·84
	99·11		100·00

Three double salts have been made by dissolving lead bromide in solutions of cæsium chloride. The analyses show that the two salts do not combine unchanged, but that there is usually an extensive exchange of halogens. Each of the products must be considered, therefore, as a mixture of a double chloride with the corresponding double bromide.

$Cs_4Pb(Cl, Br)_6$.—This was produced in rhombohedrons, like the chloride and bromide. Two crops were analyzed.

	Found.	
Cæsium	54·65	55·50
Lead	19·30	18·61
Chlorine	15·89	19·90
Bromine	9·52	4·03
	99·36	98·04
Ratio, Br : Cl	1 : 3·8	1 : 11·2

$CsPb(Cl, Br)_3$.—This occurred in small rectangular prisms, like the chloride and bromide and having a yellow color intermediate between them. Two crops gave the following analyses:

	Found.	
Cæsium	30·24	30·50
Lead	44·23	43·55
Chlorine	21·44	18·94
Bromine	4·00	8·79
	99·91	101·96
Ratio Br : Cl	1 : 12	1 : 4·8

$CsPb_2(Cl, Br)_5$.—This was obtained in white plates resembling the two double salts. Two products were analyzed.

	Found.	
Cæsium	18·94	----
Lead	51·40	51·97
Chlorine	16·29	19·31
Bromine	13·27	8·62
	99.90	
Ratio Br : Cl	1 : 2·8	1 : 5

The Potassium Lead Halides.

In studying these bodies care has been taken to record the conditions under which they were made. These conditions, in many cases are only approximately given, because uncertain quantities of salts had often been removed from the solutions, either for analysis or in order to obtain smaller and better crops of crystals. A large number of analyses have been made in some cases. This was due to the fact that the salts often varied so little in appearance that it was necessary to analyze many products in order to identify them and to be certain that they were not different compounds.

$3KPbCl_3 . H_2O$.—When lead chloride is dissolved in a hot solution of potassium chloride which is so concentrated as to be nearly saturated when cold, this double salt is deposited on cooling. It forms brilliant prismatic crystals which are largest in the most concentrated potassium chloride solutions. The largest crystals obtained had a length of more than 10^{mm} and a diameter of 1 or 2^{mm}. It was noticed that, when sufficiently concentrated solutions were used, pure potassium chloride crystallized upon this compound, and no evidence was obtained of the existence of a double salt containing a larger proportion of potassium chloride than this.

The following table gives the approximate conditions under which the five samples which were analyzed were made.

	KCl.	$PbCl_2$.	Volume.	Volume for 1gKCl.
A	400g	80g	1100cc	$2\frac{3}{4}$cc
B	400	80	1200	3
C	150	40	450	3
D	100	25	350	$3\frac{1}{2}$
E	300	55	1300	$4\frac{1}{3}$

The results of the analyses are as follows:

	A.	B.	C.	D.	E.	Calculated for $3KPbCl_3 . H_2O$.
K	11·38	11·10	10·79	....	....	10·90
Pb	57·46	57·68	57·43	57·94	57·14	57·73
Cl	29·91	29·87	29·81	....	....	29·70
H_2O	1·45	1·39	....	1·51	1·88	1·67
	100·20	100·04				100·00

All the samples were thoroughly air-dried before they were analyzed. By this treatment the crystals did not lose any of their luster. A finely pulverized portion of sample A lost only 0·02 per cent in weight after standing over concentrated sulphuric acid for eight days. The same sample suffered an additional loss of 0·23 per cent when heated for twelve hours in a steam drying-oven. The water was not rapidly given off until a temperature of about 200° was reached. The salt decrepitates when heated rapidly to about 200°, corresponding in this respect to the salt which Remsen and Herty described as anhydrous and to which they gave the formula $KPbCl_3$. There can be no doubt, therefore, that Remsen and Herty's formula is incorrect.

KPb_2Cl_5.—This salt is formed in more dilute solutions than those which produce the previously described compound. It occurs, like that compound, in white prismatic crystals, but it differs considerably from it in luster and form, so that the two salts can be distinguished by microscopic examination. The salt under consideration is anhydrous, and this fact makes it easy to distinguish this compound, when pure, from the other.

Four analyzed crops were made under the following conditions:

	KCl.	$PbCl_2$.	Volume.	Volume for 1gKCl.
A	200g	50g	1500cc	$7\frac{1}{2}$cc
B	150	30	1100	$7\frac{1}{3}$
C	150	20	1100	$7\frac{1}{3}$
D	250	55	1200	$4\frac{8}{10}$

The analyses were as follows:

	A.	B.	C.	D.	Calculated for KPb_2Cl_5.
Potassium	6·14	5·97	6·18	6·07	6·20
Lead	64·74	66·43	65·85	65·72	65·65
Chlorine	28·11	----	28·13	28·08	28·15
Water	0·11	----	----	----	0·00
	99·10		100·16	99·87	100·00

There was no indication of the formation of any other double chloride as the dilution was increased beyond that given for the above products, and when a solution containing 1^g of KCl in 11^{cc} was used pure lead chloride was deposited.

$K_2PbBr_4 . H_2O$.—This salt is obtained by dissolving lead bromide in the most concentrated solutions of potassium bromide. It forms brilliant, prismatic crystals which are permanent in the air. The largest of these which were obtained were about 1^{mm} in diameter and 5^{mm} in length. A number of crops were made under the following conditions:

	KBr.	$PbBr_2$.	Volume.	Volume for 1gKBr.
A	400^g	70^g	700^{cc}	$1\frac{5}{4}$
B	400	90	700	$1\frac{3}{4}$
C	400	120	800	2
D	400	130	650	$1\frac{6}{10}$
E	500	130	850	$1\frac{7}{10}$
F	500	130	775	$1\frac{6}{10}$

These products gave the following analyses:

	K.	Pb.	Br.	H_2O.	
A	12·51	34·25	51·47	2·50	= 100·73
B	12·21	34·59	51·21	2·51	= 100·52
C	11·89	34·47	51·14	2·44	= 99·94
D	12·37	34·50	51·35	....	
E	....	34·26	51·40	2·61	
F	12·70	33·89	51·46	2·57	= 100 62
Calculated for $K_2PbBr_4 . H_2O$	12·55	33·21	51·35	2·89	= 100·00

This salt is apparently stable in the air, but it loses water very slowly over sulphuric acid. A finely powdered sample of A lost 0·23 per cent after remaining 12 hours in the desiccator, and the same portion suffered an additional loss 0·33 after eight days. A sample which was not pulverized lost only 0·09 per cent in 12 hours and, in addition, 0·17 per cent in eight days. About one-half of the water went off when the substance was heated for 12 hours in a steam drying-oven. At 200° the water is rapidly and completely expelled.

$3KPbBr_3 . H_2O$.—The conditions under which this salt can be made are rather narrow, and these conditions encroach upon those of the preceding compound, so that small differences in the amounts of lead chloride used or in the temperature of the solution are sufficient to cause the formation of the other salt. It forms brilliant, colorless, lozenge-shaped crystals which can be easily distinguished from the other compound. The crystals which were obtained sometimes had a diameter of 2 or 3^{mm}.

The crops analyzed were made under the following conditions:

	KBr.	$PbBr_2$.	Volume.	Volume for 1g KBr.
A	500^g	130^g	950^{cc}	$1\frac{9}{10}$
B	500	130	1050	$2\frac{1}{10}$
C	500	140	900	$1\frac{8}{10}$
D	500	120	1050	$2\frac{1}{10}$
E	500	120	1125	$2\frac{1}{4}$

The analyses were as follows:

	K.	Pb.	Br.	H_2O.	
A	8·44	41·91	----	1·29	
B	8·02	42·71	48·95	1·62	= 101·30
C	8·60	41·61	49·16	1·60	= 100·97
D	8·08	42·69	48·91	1·14	= 100·82
E	----	42·61	----	1·17	
Calculated for $3KPbBr_3 . H_2O$	7·95	42·06	48·77	1·22	= 100·00

The salt is stable in the air. A sample, after standing seven days over sulphuric acid, lost only 0·04 per cent. The water is given off very slowly at 100°.

$KPbBr_3 . H_2O$.—This salt was described by Remsen and Herty. At summer temperature, about 25°, I was unable to obtain it, but by placing the mother-liquors from the preceding salt in an ice-chest, beautifully crystallized crops of it were obtained.

Its formation was also noticed at laboratory temperatures when the weather was somewhat cooler than in mid-summer. It forms prismatic crystals. Some of those obtained were about 10^{mm} long and 2^{mm} in diameter. Two crops were analyzed.

	Found.		Calculated for $KPbBr_3 . H_2O$.
Potassium	8·24	7·90	7·76
Lead	41·23	41·20	41·06
Bromine	47·81	----	47·61
Water	3·28	3·64	3·57
	100·56		100·00

The salt is usually permanent in the air, but in dry weather the crystals gradually become opaque, and over sulphuric acid about two thirds of the water is rapidly given off.

KPb_2Br_5.—This salt crystallizes in square plates, sometimes 3 or 4^{mm} in diameter. It can be readily distinguished from the other double bromides, not only by its form, but from the fact that it quickly assumes a pale green color when exposed to daylight. On long exposure, or in direct sunlight, this color changes to a pale dirty-brown. I have observed that lead bromide itself becomes nearly black on long exposure to daylight. This fact does not appear to be generally known.

The samples analyzed were made under the following conditions:

	KBr.	$PbBr_2$.	Volume.	Volume for 1gKBr.
A	400^g	130	1050^{cc}	$2\frac{2}{3}$
B	400	150	1250	$3\frac{1}{8}$
C	200	75	1000	5

The results of the analyses are as follows:

	A.	B.	C.	Calculated for KPb_2Br_5.
Potassium	4·75	4·75	4·71	4·58
Lead	49·22	49·11	48·48	48·53
Bromine	47·03	46·98	46·89	46·89
	101·00	100·84	100·08	100·00

$KPbI_3.2H_2O$.—It has already been mentioned that this is the only double iodide that either Remsen and Herty or I have been able to make. It forms slender, pale yellow needles, and is produced under a great variety of conditions. Two samples were analyzed. A was made with about 450^{g}KI, 75^gPbI_2, and 600^{cc} volume. For B about 400^{g}KI, 45^gPbI_2 and 280^{cc} volume were used.

	A.	B.	Calculated $KPbI_3.2H_2O$.
Potassium	6·03	6·07	5·90
Lead	30·73	30·13	31·21
Iodine	57·57	56·99	57·46
Water	5·26	6·04	5·43
	99·59	99·23	100·00

The salt is apparently stable in the air, but it loses water in the desiccator.

Sheffield Scientific School.
New Haven, Conn., October, 1892.

Art. XVII.—*The Ceratops Beds of Converse County, Wyoming;* by J. B. Hatcher.

In the December number of this Journal for 1889, Prof. O. C. Marsh gave the name Ceratops beds to certain strata in the upper Cretaceous of Wyoming, Montana, and Colorado, containing the remains of horned Dinosaurs (*Ceratopsidæ*) and many other reptilian and mammalian forms.

Of these beds, those in the northeastern portion of Converse county, Wyoming, are best known and have been most thoroughly explored. Fully ninety per cent. of all the vertebrate fossils described by Prof. Marsh from the Ceratops beds were found in this region. This fact is sufficient to warrant a more detailed description of the stratigraphical and geographical position of the beds, and of their geological and lithological characters, than has yet appeared. Not only has this region proved especially rich in vertebrate fossils, but the Ceratops beds seem to have attained a greater development here than has been noticed elsewhere. Since the present border of the beds is nearly that of the eastern shore of the fresh-waters in which they were deposited, and erosion has exposed many continuous sections in them down through the underlying Fox Hills sandstones and into the Ft. Pierre shales, this region offers exceptional advantages for determining the position of the Ceratops beds and for establishing their age upon stratigraphical as well as paleontological evidence.

Geographical Position of the Ceratops Beds.

The Ceratops beds of Wyoming have thus far been explored only in a very limited region in the northeastern part of Converse county. Going north from Lusk, a small station on the Freemont, Elkhorn, and Missouri Valley railroad, they first appear about twenty-five miles from that place, occupying the summit and northern slope of a yellow sandstone ridge extending in a westerly direction from Buck creek to Lance creek and crossing the latter stream near the mouth of Little Lightning creek, a small tributary from the west. A short distance west of Lance creek, the Ceratops beds pass under other beds composed of very similar material, and presumably of Cretaceous age. From Buck creek, the eastern border of the Ceratops beds has been traced in an almost continuous exposure, extending northeasterly to the Cheyenne river, and crossing this stream a short distance below the mouth of Lance creek. From this point, it takes a more

northerly direction, and skirting the western slope of the Black Hills, it has been traced to the north line of Converse county and on into Weston county. As stated above, the eastern shore of the fresh-waters in which the Ceratops beds were deposited was nearly that of the present border of these beds. The eastern limit of the fresh-waters was confined to the western slope of the Black Hills and that chain of minor uplifts connecting them with the Laramie range to the southwest. The Black Hills were at one time connected with the Laramie range through the Rawhide range and a less elevated series of uplifts extending in a northeasterly direction from the latter to the southern limit of the Black Hills. Remnants of this connecting range are still to be seen in the bluff just back of Lusk, known as Silver Cliff; on Duck creek two and one-half miles a little west of north of Lusk; near the head of Old Woman creek, about six miles north of the last mentioned place; in the ridge on the east side of Sage creek, two miles below Hat Creek post-office and eight miles northeast of the locality just mentioned; in another bluff ten miles below this and on the same side of the creek, but farther to the east; and doubtless in many other places as yet unobserved. The Ceratops beds were originally confined to the western slope of the Black Hills and of the less elevated series connecting the latter with the Rawhide range. This is conclusively shown by the absence of the Ceratops beds not only on the eastern slope of this range where they could have been removed by erosion, but in the region to the eastward where all the beds are approximately horizontal, and where, if they ever existed, remnants of them, at least, should yet be seen. The surface of the region to the east of the Black Hills and their southwestern extension, as just described, is composed for the most part of Miocene deposits, with many sections showing the underlying beds. In all such exposures in this region, hundreds of which have been examined, the Miocene is underlaid by marine Cretaceous or older formations. In no instance have the Ceratops beds been observed east of the Black Hills or their less elevated continuation to the southwest.

The Ceratops beds proper, that is, those beds containing remains of the *Ceratopsidæ*, are known to have a surface exposure in that portion of Converse county embraced within their eastern and southern border, as defined above, and a line extending from that point on the latter where it passes under the overlying beds a short distance west of Lance creek, nearly due north to Weston county; i. e. the country drained by lower Lance, Lightning, Cow, Doegie, and Buck creeks, and that portion of the Cheyenne river and its tributaries between the mouth of Lance creek and the north line of

Converse county. The creeks mentioned in this paper will be found on any good map of Wyoming.

Description of the Deposits.

The Ceratops beds are made up of alternating sandstones, shales, and lignites, with occasional local deposits of limestones and marls. The different strata of the series are not always continuous, a stratum of sandstone giving place to one of shales and *vice versa*. This is especially true of the upper two-thirds of the beds. The lack of continuity in the different strata has rendered it well nigh impossible to establish any definite horizons in the upper members of the series. All the deposits of the Ceratops beds of this region bear evidence of having been laid down in fresh-waters. Among the invertebrate fossils found in them, only fresh-water forms are known. There is no evidence that marine or brackish-waters have ever had access to this region since the recession of the former at the close of the Fox Hills period.

The sandstones largely predominate in the lower members of the beds. They are always fine-grained, massive to well-stratified, and nearly white to yellowish brown in color. They are occasionally compact and hard, but for the most part quite soft and friable. They are composed of sharp, angular grains of quartz with some clay and mica, the whole being loosely cemented together with carbonate of lime. Almost everywhere in the sandstones are numerous concretions of varying size and shape. Some are almost perfect spheres and vary from the size of a marble to 18 or 20 feet in diameter. Others are from a few inches to several feet in transverse diameter and sometimes several hundred feet in length, a cross section forming a nearly perfect circle. Others still are very irregular in form. These concretions usually show no concentric structure, and while they sometimes enclose foreign objects, as a *Triceratops* skull or a single bone as a nucleus, they are for the most part simply centers of solidification and not true concretions. This is frequently shown by the cross-bedding in them, so often seen in the sandstones themselves.

The shales are almost entirely wanting in the lower 400 feet of the Ceratops beds, but they are well represented in the succeeding series. They are quite soft and loosely compacted, composed mostly of clay with more or less sand in places. The prevailing color is dark brown, but they are sometimes red or bluish. They are well stratified and finely laminated, and contain occasional limestone concretions enclosing numerous invertebrates.

The lignites occur in thin seams, never more than a few inches thick, of only limited extent, and with many impurities. At no place in the Ceratops beds of this region have workable coal beds been found. These do occur, however, in the Ceratops beds of Montana. The best exposure of them observed there is in Fergus county, on Dog creek, about 15 miles from its mouth, just above where it enters the Bad Lands of the Missouri. Workable coal seams occur in Wyoming, in the beds west of Lance creek, which overlie the Ceratops beds, and will be referred to later.

Intercalated with the sandstones, shales, and lignites, are quite local deposits of limestones, clays, and marls. The latter are composed almost entirely of fresh-water shells, fragments of bone, teeth, etc.

Along their southern and eastern border, the Ceratops beds dip to the northwest, at an angle of about 16° between Buck creek and Lance creek. One half mile east of Lance creek, the dip is 29° to the northwest. This angle of inclination rapidly diminishes toward the interior, and is scarcely noticeable in the vicinity of Lightning, Cow, and Doegie creeks. The fold is quite abrupt as is further shown by cracks which were made in the strata at the time of disturbance at right angles to their dip and parallel with their strike. These fissures have been filled by infiltration with materials now harder than those forming their walls, and now appear in many places as projecting veins, from a fraction of an inch to a foot or more in width, and from a few yards to several hundred in length.

Stratigraphical Position of the Ceratops Beds.

The Underlying Beds.—Along their southeastern border, especially between Lance and Buck creeks, are many fine exposures of the Ceratops beds and the underlying Fox Hills. Perhaps the best exposure is that made by a small tributary emptying into Buck creek, about four miles east of Lance creek and one-half mile northwest of the Buck creek pens used by the cattle men for round-up purposes. This watercourse has here cut its way in a southeasterly direction, at right angles to the strike, down through the lower half of the Ceratops beds, through the underlying Fox Hills sandstones, and into the Ft. Pierre shales. At this place, the bed of Buck creek and the rounded hills of that region at the head of this stream, embraced between the border of the Ceratops beds and Fox Hills sandstones on the north and the bluffs of Miocene clays and conglomerates on the south, are composed of Ft. Pierre shales. All the strata of this entire section dip to

the northwest at an angle of 16°. The exposure is a continuous one, and commencing from below, the section is as follows:

At the base are the Ft. Pierre shales of unknown thickness, several hundred feet of which are exposed. They consist of argillaceous, finely laminated, dark shales, quite soft and easily eroded. They contain many limestone concretions and numerous invertebrates; among others are *Baculites ovatus*, *B. compressus*, *Scaphites nodosus*, *Placenticeras placenta*, *Nautilus Dekayi*, etc.

Overlying the Ft. Pierre deposits is an alternating series of sandstones and shales with an estimated thickness of 500 feet. In the lower portion of this series, the shales predominate, but toward the middle the sandstones are in excess, and in the upper 50 feet they entirely replace the shales. The sandstones are of a yellowish brown color, very fine grained, firm, and well stratified below, but softer, and quite massive at the top, where they contain numerous large concretions and a rich marine invertebrate fauna. Representatives of this fauna have been sent to Mr. T. W. Stanton of the U. S. National Museum, and were pronounced by him to be characteristic of the uppermost Fox Hills in direct conformity with their stratigraphical position.

The Ceratops Beds.—Next come the Ceratops beds with an estimated thickness of 3,000 feet, resting directly upon the Fox Hills series. Immediately above the Fox Hills is a very thin, but quite persistent, layer of hard sandstone, well stratified, and quite cleavable along the lines of stratification. This stratum of sandstone is about six inches thick, and is regarded as the dividing line between the marine and fresh-water beds. It is overlaid by about 150 feet of yellowish brown, well-stratified sandstones apparently non-fossiliferous. These are in turn overlaid by about 250 feet of almost white, fine-grained, massive sandstones with numerous concretions, but no fossils were found in them. Next comes the fossiliferous portion of the Ceratops beds, consisting, as before stated, of alternating sandstones, shales, and lignites.

All the beds of the entire section are conformable, and bear evidence of a continuous deposition, from the Ft. Pierre shales up through the Fox Hills sandstones and the overlying fresh-water Ceratops beds. The Ft. Pierre shales are not suddenly replaced by the Fox Hills sandstones, but the transition is a gradual one, and it is impossible to say just where the one ends and the other commences. The same is true of the beds overlying the Fox Hills. The thin seam of hard sandstone, just referred to as separating the fossil-bearing Fox Hills sandstones below from the very similar non-fossiliferous sandstones

above, is here regarded as the dividing line between the Fox Hills and Ceratops beds. But this decision, it must be admitted, is quite arbitrary, and the evidence in its favor is negative rather than positive. The only reason for placing the overlying 400 feet of non-fossiliferous sandstones in the fresh-water series is the absence of fossils in them, which may perhaps be accounted for by the destruction of the marine forms brought about by the change from salt to fresh-waters. The overlying non-fossiliferous beds may have been deposited in the fresh-waters before fresh-water forms had distributed themselves over this region. The sandstones of the entire series are very similar, and since there is entire conformity throughout, it is absolutely impossible to determine just where the marine beds end and the fresh-water beds commence. The Ceratops beds of this region are a natural sequence of the Fox Hills. The materials composing both were evidently derived from a common source. The only safe criteria for distinguishing one from the other are their fossils.

The Overlying Beds.—Along their eastern border, the Ceratops beds are occasionally unconformably overlaid by Miocene clays and conglomerate. But these deposits, if they ever extended over any considerable portion of the region now occupied by the Ceratops beds, have been almost entirely removed by erosion. To the west of Lance creek, the Ceratops beds pass under a very similar series of sandstones, shales, and lignites, of about the same thickness, and conformable with them. In this series, the sandstones are more massive than the underlying sandstones; the shales contain more sand; and the lignites are more frequent, of a better quality, and attain a greater thickness, as shown at the Shawnee coal-mine on Shawnee creek, where a single bed of coal is 10 feet thick, and of a quality sufficiently good to enable it to be profitably mined for commercial purposes. Thus far no vertebrate or invertebrate fossils have been found in these beds, but they contain a rich fossil flora, representatives of which have been sent to Prof. F. H. Knowlton of the National Museum, with a request for his opinion as to the age of the beds, based upon the evidence afforded by the fossils. Upon no other evidence than a general similarity to known Laramie deposits in other regions, they are here regarded as Upper Laramie.

Age of the Ceratops Beds.

In a series of articles commencing in the April number of this Journal for 1889, Prof. Marsh has referred the Ceratops beds to the Laramie, mainly upon evidence afforded by their vertebrate fossils. Owing to the fact that very few vertebrates

had previously been described from the typical Laramie, as first defined by Mr. Clarence King, and the consequent lack of vertebrate forms known to have come from the Laramie for comparison with those found in the Ceratops beds, it must be admitted that the vertebrate fauna of the latter is, in itself, at present not sufficient proof to establish the Laramie age of the Ceratops beds.

Fortunately the Ceratops beds contain an extensive invertebrate fauna, in which Dr. C. E. Beecher has identified the following: *Unio Couesii*, White, *Sphærium formosum*, M. & H., *Linnæa compactilis*, Meek, *Campeloma multilineata*, M. & H., *Tulotoma Thompsonii*, White, and others known from the typical Laramie, some of which are characteristic of it. The invertebrate fossils may, therefore, be considered as additional evidence of the Laramie age of the beds.

But the most conclusive evidence that the Ceratops beds belong to the Laramie period is that afforded by their actual position in regard to the Fox Hills. As stated above, they conformably overlie the Fox Hills, which is the normal position of the Laramie. This conformability must be regarded as an actual and not an apparent one, since it is shown in an almost continuous exposure for many miles along the southeastern border of the beds, where they are upturned at an angle of from 16° to 29°, and where an unconformability, if any existed, would be plainly visible.

The evidences in favor of referring the Ceratops beds to the Laramie are:

(1) They conformably overlie the Fox Hills sandstones and contain both a reptilian and a mammalian fauna, with decided Mesozoic affinities. Among the reptiles, the Dinosaurs are, in degree of development and point of numbers both as to individuals, and genera and species represented, probably unsurpassed in any previous similar division of the Mesozoic; while as regards degree of specialization, they are superior to all previous forms. This age was preëminently an age of reptiles.

(2) They contain an invertebrate fauna comprising many forms identical with those already described from the typical Laramie, some of which are unknown except in the Laramie.

(3) They immediately and conformably overlie the Fox Hills, and show evidence of a continuous deposition through both series.

Probable Conditions attending the Deposition of the Ceratops Beds.

The change from marine to fresh-waters which took place at the close of the Fox Hills and the beginning of the Laramie was brought about by the great continental elevation going on

in previous Cretaceous periods, and sufficient to cause a recession of the salt waters at the close of the Fox Hills. During the Laramie, this region was occupied by fresh-waters or in places by dry land.

This period of elevation which brought about the close of the marine Cretaceous is thought to have been followed by a period of subsidence during the Laramie. For, since the beds of the Laramie were evidently deposited in shallow waters, as is abundantly shown by the great number of lignite seams which they contain, and still further in the Ceratops beds, at least, by the absence of continuity of strata, frequent cross-bedding, etc., it is impossible to account for so great a thickness of beds, all bearing evidence of having been deposited in shallow waters, except on the theory of a subsidence going on over the region during the period in which they were laid down. This subsidence must have been so gradual that the upbuilding by sedimentation at the bottom of the waters kept pace with the subsidence; any increase in the rate of the latter increasing the depth of the waters, and a decrease in the rate of subsidence causing a decrease in depth. The latter would bring about a condition requisite for the deposition and preservation of vegetable matter which would be transformed later into lignites.

The Ceratops beds are thought to afford evidence in themselves of having been deposited not in a great open lake, but in a vast swamp, with occasional stretches of open waters, the whole presenting an appearance similar to that which now exists in the interior of the Everglades of Florida. This condition would account for the frequent changes from one material to another in the same horizon, before referred to. In some places in the beds, these changes are quite frequent, strata of sandstones and shales replacing one another in great confusion. It would also explain the cross-bedding so often seen in the sandstones of this region, in localities remote from the present border of the beds, and hence far removed from the shore of the ancient lake or swamp. This cross-bedding could hardly occur in off-shore deposits of a great fresh-water lake of any considerable depth.

The conditions that prevailed over this region during the period in which the Ceratops beds were deposited were probably those of a great swamp with numerous small open bodies of water connected by a network of water courses constantly changing their channels. The intervening spaces were but slightly elevated above water level or at times submerged. The entire region where the waters were not too deep was covered by an abundant vegetation, and inhabited by the huge Dinosaurs (*Triceratops*, *Torosaurus*, *Claosaurus*, etc.), as well

as by the smaller crocodiles and turtles, and the diminutive mammals, all of whose remains are now found imbedded in the deposits. That these animals at one time inhabited the very region where they now lie entombed is conclusively shown by the occasional finding of entire skeletons with every bone in place, at localities far distant from the border of the beds, and in a state of preservation which could not possibly exist had they lived and died on a distant shore, and their carcasses been transported by the waters to their present resting places after death. Moreover, skeletons are sometimes found in an upright position or inclined to one side or the other, showing that the individual met death by miring in the immediate spot where the remains now rest. A noteworthy example of this was that of the skeleton of a Dinosaur discovered in August, 1891, by Mr. A. L. Sullins, and recently described by Prof. Marsh as *Claosaurus annectens.** This skeleton when found was in a partially erect position, the limbs extended, and every bone in its natural position except where exposed and worn away by recent weathering. The ribs were still distended, retaining the exact form and capacity of the thoracic and abdominal cavities. The whole showed that the animal in its wanderings had mired in the quicksands, and in its struggles for liberation had been engulfed by them.

In the sandstones of the Ceratops beds hardly a fossil bone of any considerable size is to be found that does not bear evidence of having been dropped in shallow waters. In many instances, it is still possible to determine the direction of the currents which succeeded in burying the bones, and thus prevented their decay. For instance, on one side of a bone the matrix will be made up entirely of sand, while on the opposite side the stems and leaves of plants have been dropped, and, now partially lignitized, form a considerable portion of the matrix. This arrangement of the materials of the matrix in which the bone is imbedded shows the direction of the current to have been from that side containing only sand, and toward the side containing the plants. So shallow were the waters, the bone itself became an obstacle sufficient to produce an eddy on its lower side, in which the leaves and other vegetable materials accumulated, and sank to the bottom.

Conclusions.

If the Ceratops beds of Converse county, Wyoming, are the equivalents of the typical Laramie of southwestern Wyoming, the remarkable vertebrate fauna of the former will prove of great importance in determining the age of other beds now

* This Journal, vol. xliii, p. 453, May, 1892; and vol. xliv, p. 171, Aug., 1892.

in doubt, containing like or similar faunas. Notably among the latter are the Denver and Arapahoe beds in the vicinity of Denver, Colorado, and their probable equivalents in other portions of the same state, recently described by Mr. Whitman Cross, as "The Post Laramie Deposits of Colorado."* Mr. Cross refers these beds to a period later than the Laramie on account of unconformities existing, in some places, at least, between them and the underlying recognized Laramie and older Cretaceous formations, and in opposition to the evidence afforded by the vertebrate fossils thus far obtained in them. Whether it is better to ignore the evidence afforded by the vertebrate fossils, or to treat these unconformities as local, remains to be decided by future investigations. It is quite possible that Dinosaurs continued into the early Eocene, but they were represented there, if at all, only by degenerate types, and less specialized forms. It would certainly be remarkable, not to say impossible, that a group of Dinosaurs showing so great a development and marked specialization as are to be seen in *Triceratops* and *Claosaurus* should continue uninterruptedly from near the base of the Laramie up into the Tertiary. Nevertheless at least two species of *Triceratops* have been described from the Denver beds referred by Mr. Cross to the Post-Laramie. Regions affording such contradictory evidences should be thoroughly examined, and, where possible, their actual stratigraphical relations should be determined. Results thus attained might be sufficient to harmonize observations now in apparent opposition.

Yale Museum, New Haven, Conn., December 5, 1892.

Art. XVIII.—*On the Use of Planes and Knife-edges in Pendulums for Gravity Measurements*;† by T. C. Mendenhall.

In the theoretical discussion of the pendulum it is usual to assume that it vibrates about an axis which is a straight line. In practice it is generally attempted to realize this condition as nearly as possible and the method almost if not quite universally adopted has been to attach what is technically known as a knife-edge to the pendulum and allow it to rest upon a suitably supported plane horizontal surface. The axis about which rotation takes place is at any moment determined by the contact of the edge with the plane surface. To satisfy theoretical conditions it is evident that this edge must be

* This Journal, vol. xliv, p. 19, July, 1892.

† Read at the meeting of the National Academy of Sciences, Nov. 3, 1892.

formed by the intersection of two perfectly plane surfaces, a condition which can never be quite realized in practice. It is important, therefore, to inquire how it may be most nearly approached and especially by what disposition of parts, both as to form and arrangement, a given departure from it will produce the minimum effect upon the period of the pendulum and upon the value of the force of gravity obtained by its use.

What is believed to be an important departure from the universal practice in regard to the arrangement of parts has recently been experimentally investigated and with very satisfactory results. It consists in an exchange in place of the knife-edge and plane, the latter being attached to the pendulum and the former to the fixed support. This arrangement offers many advantages to which it is desirable to invite attention. It will be best, however, to refer in the beginning to what will at once suggest itself to many as a serious objection to this plan. When the knife-edge is attached to the pendulum it may be assumed to have a constant relation to its mass, at least so long as the pendulum does not suffer an injury which alters its configuration. The axis about which vibration takes place may therefore be regarded as constant as far as relates to different sets of swings, and it will be practically indifferent as to what part of the supporting plane it rests upon. When the plane is attached to the pendulum this axis of vibration is entirely determined by the position of the plane upon the knife-edge.

This difficulty, which at first sight appears to be formidable, readily disappears in practice. In fact, a little calculation will show that the line of contact between the knife-edge and the plane must vary in position by a relatively large amount in order to effect sensibly the period of the pendulum. Even if the placing of the pendulum for successive swings were accomplished by no more accurate devices than the eye and hand, it would not be difficult to avoid sensible error from this source. The apparatus by means of which the pendulum is lifted from and lowered upon the knife-edge is readily made adjustable so that any desired line of contact can be secured and retained indefinitely.

As an illustration of the constancy of period of a pendulum arranged in this way, as well as showing the ease and accuracy with which the period of vibration is ascertained, the following results are exhibited.

They show the period of the pendulum derived from individual swings extending through about an hour each. Twelve such swings were distributed nearly uniformly through a period of twenty-four hours, in order to eliminate any effect of irregular hourly rate of the chronometer. The figures as

shown below include this effect, of course, it being eliminated only from their mean.

The two sets shown were made for the purpose of determining a "pressure coefficient," the first being made in air at a pressure of 25^{mm} and the second at a pressure of 600^{mm}. It will be seen that in no case does the variation from the mean amount to as much as one part in a million, a constancy which leaves little to be desired.

Pres. 25^{mm}. Period	v.	Pres. 600^{mm}. Period	v.
·5006904	— 4	·5007368	+ 4
901	— 1	74	— 2
898	+ 2	71	+ 1
900	0	73	— 1
902	— 2	72	0
899	+ 1	75	— 3
901	— 1	73	— 1
898	+ 2	71	+ 1
896	+ 4	70	+ 2
902	— 2	68	+ 4
899	+ 1	69	+ 3
900	0	75	— 3
Mean ·5006900		Mean ·5007372	

The advantages of the new form of pendulum will be made evident on an examination of its application to the differential method or use of a so-called invariable pendulum as well as to the reversible form for absolute determinations of gravity.

There is an advantage in the matter of construction. It is not easy to insert the knife-edge in the head of the pendulum so that it shall be at right angles to the axis of symmetry of mass. The plane used in its stead may be accurately adjusted by simple optical methods.

The advantage of the plane in the matter of permanency or invariability is so evident as hardly to need remark. The knife-edge is usually the most delicate part of a pendulum, that most liable to be injured and generally incapable of being repaired when once damaged. In an invariable pendulum the knife-edge cannot be reground or replaced by another, without destroying the identity of the whole so that swings at different places or times are no longer comparable with each other. A pendulum carrying a plane instead of a knife-edge is evidently vastly less liable to accidental injury and is entitled in a much greater degree to the name "invariable." The knife-edge being no longer an integral part of the vibrating mass can be reground or replaced at will. In fact in practice it is desirable to have several knife-edges and in an extensive pendulum campaign a "standard edge" will be used

upon which swings will only rarely be made in order to detect any deterioration which may take place in those in daily use. Knife-edges of different material may also be used if such a course is found to be desirable.

In the reversible pendulum for absolute measures, in addition to the advantages already described there is also the very important fact that the measurement of the length of the pendulum is likely to be more accurate. Whether the knife-edge is a part of the pendulum or of the fixed support, a certain amount of elastic compression will always take place when the weight of the pendulum is upon it and this is likely to be relatively greater the more perfect the edge. If the knife-edge is a part of the pendulum the length of the latter must be greater when vibrating than when at rest and supported with the edge free for length measurement.

The measurement of the distance between the two knife-edges of a reversible pendulum as ordinarily made is a matter of much difficulty. It is believed that without resorting to extraordinary methods the distance between the two planes of the newly constructed reversible pendulum will be capable of measurement with higher accuracy and if necessary or desirable, recourse may be had to the method of Michelson and Morley for relating the distance between surfaces to the length of light waves.

Perhaps the most important gain thus far from the new arrangement is that it has made it possible to investigate the knife-edge, as to form and material, with an ease and thoroughness hitherto unattainable. As long as the knife-edge forms a part of the pendulum it is impossible to study the effects of variation in its angle, width or material because every such alteration must necessarily alter the vibration-period by changing the mass and form. With the new form this difficulty no longer exists; the vibrating body remains constant in mass and configuration and any change in its period is due to the influence of the knife-edge.

Some of the results already obtained are of sufficient interest to justify their publication in advance of a full and complete investigation now in progress.

In order to investigate the effect of a wearing or slight flattening of the edge, such as may, and in fact does result from long and not too careful use, a steel knife-edge was used, the plane, forming a part of the pendulum, being of agate. A steel edge was used on account of the greater ease with which it could be manipulated in grinding. The agate knife-edge has been in general use, but experiment showed that both steel and agate being made as perfect as possible, the vibration periods were essentially the same. The angle which the two

planes forming the edge made with each other was 110°. The edge was first ground until it was pronounced as perfect as was practicable by the artist, Mr. E. G. Fischer, chief mechanician of the Coast and Geodetic Survey, who has shown rare ingenuity and skill in the solution of the mechanical problems arising during the investigation. The width of the edge was then measured, using a microscope magnifying from 100 to 500 times. This was a difficult operation, the question of illumination being troublesome. It seemed tolerably certain, however, that the width of such an edge was not greater than 1^{μ} ($\cdot 001^{mm}$) Several different edges ground in this way were measured with essentially the same result. After the vibration period on one of these had been ascertained it was given one or two light touches upon the stone, producing an edge which was found on measurement to be approximately 2^{μ} in width. After the pendulum had been swung on it it was still further flattened.

Theory shows that a pendulum will vibrate more rapidly upon a slightly flattened or rounded edge than upon one which is perfect. The table below shows the results of experiment conducted as above described. The pendulum used was one of the short, approximately half-second, pendulums of the form referred to a year ago.* The numbers showing the width of the knife-edge must be regarded as approximations only but they are probably relatively not far from correct.

They indicate very clearly and positively the important part played by the knife-edge and the importance of having it perfectly ground. There is good reason to believe that this matter has not hitherto received that attention in pendulum researches which it is here shown to demand. While the effect of a given amount of flattening on the vibration-period would be less with a long seconds pendulum than with one of shorter period, the tendency towards flattening, arising out of greater weight and greater difficulty of handling would be very much increased. There is no doubt that in some important gravity operations knife-edges have been used which, in the light of these results must be considered intolerably poor. It will be observed that going from what may be accepted as a practically perfect edge to one only one two-hundredth of a millimeter wide, changes the period by one part in forty thousand, an amount entirely outside of a reasonable limit of accuracy for work of this kind.

The question of the best angle for the knife-edge is also important and interesting. If the material of which the edge is composed were physically perfect and if the faces were perfect planes all angles, within certain wide limits, would be

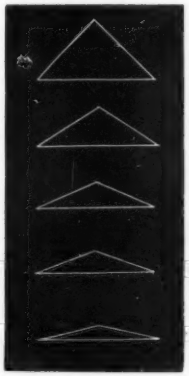
* This Journal, February, 1892.

equally good. Imperfection of substance, as to strength, continuity, etc., is the principal difficulty and this is met by making the angle of the faces as great as possible. But the errors arising from the impossibility of grinding the faces to true planes are reduced to a minimum by making the angle as small as possible and hence there is indicated an angle neither very large nor very small which is better than others. In other words, if the angle is too small the edge will be entirely crushed and thus broadened and made imperfect. If the faces are not perfect planes it is clear that the larger the angle the wider will be the limits of the horizontal projection of the line of their intersection and this will be equivalent to widening the edge upon which the pendulum swings.

It is interesting that this seems to be verified in practice, as is shown in the results given below. Edges ground to five different angles, varying from 90° to 160° were used. The results show that while there is no *great* difference in the results with the range of angles examined, it is tolerably certain that the angle should not (with this material—steel) be less than 110° nor more than 140°. An angle of 130° will probably be found the most satisfactory, combining the necessary sharpness (when properly ground) with strength to resist accidental injury or excessive elastic compression.

Steel Knife-Edge.

Width. μ	Period.	Gain.
1	·5008880	0
2	8839	41
5	8756	124
6·5	8503	377
10	7626	1254

Angle.		Period.
90°		·5008875
110°		8880
130°		8874
150°		8884
160°		8852

Steel knife-edges have been very generally used in pendulum work but they are inferior to those made of agate. The brittleness of the latter is rather an advantage than otherwise. When an agate knife-edge receives a blow sufficient to injure it, a piece is chipped out, leaving the remaining portion of the edge clean and perfect as before and the only effect on the vibratory period is that due to the removal of the matter lost. Under the same circumstances an edge of steel will be flattened or distorted and while there may be no loss of matter the edge may be made so imperfect that the period will be decidedly affected.

The grinding of an agate edge demands much more labor and skill than is required in the preparation of one of steel but it is well worth the additional cost.

It has been found that a knife-edge, even if its mass is considerable, is very susceptible to such distortion of figure as will render it imperfect. To avoid this it has been found desirable to insert the edge in a heavy tablet of brass and grind it *in situ*. The tablet is provided with three feet with hemispherical ends, resting respectively in a conical hole, a V groove and on a plane. In this way the edge is subjected to no strain after it is ground.

Art. XIX.—*Preliminary note on the colors of cloudy condensation;* by C. Barus.

By allowing saturated steam to pass suddenly from a higher to a lower temperature (jet) in uniformly temperatured, uniformly dusty air the following succession of colors is seen by transmitted white light, if the difference of temperature in question continually increases: Faint green, faint blue, pale violet, pale violet-purple, pale purple, muddy brown-orange, straw-yellow, greenish yellow; green, blue-green, gray-blue, intense blue, indigo, intense dark violet, black (opaque); intense brown, intense orange, yellow, white.

Seen by reflected white light, the same mass of steam is always dull neutral white.

If the colors enumerated be taken in the inverse order beginning with white, they are absolutely identical with the interference colors of thin plates (Newton's rings) of the first and second order, seen by transmitted white light under normal incidence. Thus it is worth inquiring whether small globules of water, when white light is normally transmitted, affect it like thin plates. For a given homogeneous color if I

be the intensity of the incident light and k (·04 to ·05) the reflection coefficient, then after a single transmission the interference maxima and minima are $(1-k)^2(1+k^2)I$ and $(1-k)^2(1-k^2)I$; they differ only very slightly. But if there be an indefinite number of particles all of the same size available, then this process is indefinitely repeated in such a way that while the colored light is not extinguished, the admixed white light becomes continually more colored. Hence after a sufficiently great number of transmissions the emergent ray will show intense color. Seen by reflected light the case is almost the converse of this. For a single particle the masses which interfere are (kI and $k(1-k)^2I$) weaker but nearly equal, and the interference is therefore very perfect. It is not, however, capable of indefinite repetition for after each interference the direction is reversed. The light which emerges in a direction opposite to the incident ray must therefore have passed through the particles, i. e. it has been brought to interference both by reflection and by transmission, and its color is thus virtually extinguished.

The final point to be considered is the occurrence of black, between brown and dark violet of the first order. Here, however, for relatively very small increase of the thickness of the plate, the colors run rapidly from brown through red, carmine, dark red-brown to violet. Hence these interferences are apt to occur together and an opaque effect is to be anticipated. Particularly is this presumable, because the opaque field is coincident with the breakdown of the steady motion* of the jet.

Thus it seems that the colors of cloudy condensation may without serious error be interpreted as a case of Newton's interferences by transmitted light. In so far as this is true one may pass at once from the color of the field to the size of the particles producing it; and the dimensions so obtained agree well with R. v. Helmholtz's estimate made in accordance with Kelvin's equation for the increase of vapor tension at a convex surface. In the study of the condensation phenomena vapor-liquid, the experimental power of a method, which is adapted for *instantaneous* observation, and which for a certain range of dimensions not only discriminate between vapor and a collection of indefinitely small suspended water globules, but actually defines their size, cannot be overestimated. An account of my work together with other allied observations will be given in the March number of the American Meteorological Journal.

*I refer here to Osborne Reynold's work (Phil. Trans., III, p. 935, 1883) with liquid jets, according to which after a certain critical velocity is surpassed, the uniformly steady motion breaks up into eddying motion. I am also searching for Reynold's lag phenomenon (l. c. p. 957).

ART. XX.—*Lines of structure in the Winnebago Co. Meteorites and in other Meteorites;* by H. A. NEWTON.

THE ground and polished surface of a Winnebago Co. meteorite showed to me some interesting markings. Subsequent examination revealed like markings in other meteorites. Perhaps these markings have been described. If so I have no recollection of the description, and therefore it seems worth while to call attention to them.

The polished surface of a small Winnebago stone, three or four square centimeters in area, shows several hundreds of bright metallic points. The larger iron particles in this surface have great varieties of shapes, — the smaller ones are usually mere points. When seen with a lens, or even at a distance from the eye suited to distinct vision there does not appear to be any regular structure or arrangement of the bright points. But if the surface is so held as to be a little beyond the place of distinct vision, and at the same time, turned around in such way as to reflect always a strong light to the eye, either skylight or lamplight, there appear lines of points across the polished surface of the stone, which suggest very strongly the Widmanstaetten figures on metallic meteorites. At times as the stone is turned no lines can be detected. Again one set of parallel lines or two sets crossing each other become visible. Some of the sets are very sharply manifested, and some are so faint as to leave one in doubt whether the lines are real or only fancied. There are on the surface in question six or eight of these sets of lines.

A second surface was ground nearly parallel to the first, at about one centimeter distant from it, and like lines appeared on this parallel surface. Some of the lines, but not all of them, corresponded in direction in the two surfaces. Four more surfaces approximately at right angles to the first surface, and corresponding to the faces of a right prism were then ground and upon these surfaces the like sets of lines appear with more or less distinctness.

A slab of a Pultusk stone 6×7 centimeters shows over its entire surface like markings. Something like a curvature of the lines appears in one instance but in general the lines run straight from side to side of the slab. The slab is six millimeters in thickness and most of the sets of lines have the same directions upon the two sides.

A Hessle stone, a small slice from the Wold Cottage stone, one from Sierra di Chaco, one from a Sienna stone, a fragment from the Rockwood stone, and a slice from the Rensselaer Co.

stone, all show with more or less clearness the like markings. Of three microscope slides of the Fayette Co. meteorite one shows them clearly, a second shows traces of them, the third not at all.

A considerable number of the ground surfaces of meteoric stones in the Peabody Museum also show these markings. For example a triangular surface of a Weston stone, 8 or 10 centimeters to each side, exhibits them very well.

These markings are such as we might expect if the forces which determine the crystallization of the nickel-iron of the iron meteorites also dominated the structure of the rock-like formations of the stony meteorites and the distribution therein of the iron particles. The relation of quartz crystals to the structure of graphic granite is naturally suggested by these meteorite markings.

Art. XXI.—*Preliminary Note of a new Meteorite from Japan;* by Henry A. Ward.

[Read before the Rochester Academy of Sciences, Dec. 12, 1892.]

Several months ago a friend, Mr. Alan Owston, who had been traveling in the interior of the main island of Japan, told me that he had seen what he thought to be a stone meteorite in a temple in Iwate. As the result of considerable correspondence this specimen has been sent to me, reaching me early in December. It was accompanied by a letter in Japanese language of which the following is a translation:

"This meteorite which I send you herewith fell about forty years ago, viz: in the 3d year of Ka-yei, at dawn on the 4th day of the 5th month, (13th June, 1850). It fell obliquely from the W.N.W. with a great sound like thunder, at the village of Kesen in the district of Kesen, in this Prefecture. It entered the ground five feet, and remained hot for two days. The original size was said to be about equal to 2½ sho of rice. This would be about 1½ cubic feet. There were ten or more pieces of it which have been distributed about in various places.

(Signed) Sato Kenji, of Nota village, Iwate Prefecture."

The specimen which I have received is $6\frac{1}{16}$ ounces in weight. Its shape is an irregular triangle about 6½ inches in its greatest (vertical) diameter, and about 5 inches thick (see figure). Two long patches an inch wide on either side of the mass are covered with crust; the rest is broken surface, showing inner

structure. This crust has the usual characteristic pittings, very clearly indented, yet shallow. It is of a dull blackish brown color, with a pebbled or grained appearance. Close examination shows numerous shining metallic points, appar-

Kesen meteorite, two-thirds natural size.

ently of iron, with reddish stains, doubtless due to the oxidation of these. This surface shows clear signs of fusion, but there is no *flow* of the melted part, which might give clue to the direction of flight of the mass. The interior shows no signs of arrangement either in planes or concentric. There are several short fine fissures or fractures from one and a half to two inches in length, some of which reach to the lower side of the surface. They are not parallel, and they were doubtless caused by the shock of reaching the earth. One inner face however seems a little smoothed, as if prior to the breaking off of the contiguous piece there had been a sliding of sur-

faces. This stone is eminently chondritic. There is a fine-grained paste, and through it are distributed little rounded grains. Both the matrix and the grains are of the same material,—the minerals olivene and enstatite. This is all that is visible to the naked eye. But an ordinary low power lens shows many bright, metallic points. Also glossy, waxy pimples of red color, perhaps an effusion of chloride of iron. Some larger blotches of iron rust occur here and there. In determining the metallic portion of the meteorite (which has been done by Mr. John M. Davison of the Reynolds Laboratory of the University of Rochester), pieces of the mass were finely crushed and the metal separated by the magnet, washed in alcohol and dried rapidly. Its weight having been taken, it was dissolved in nitric acid, and a little insoluble stony matter was separated, weighed and deducted from it. A mean of two determinations made in this way gave the metallic proportion about 16 per cent of the whole mass. This is an unusual per cent of metal,—much more than in the Waconda, which stone resembles in some respects the Kesen,—which we now name this new meteorite from Japan.

We are expecting to soon receive some other pieces, which may give new facts; and also a fuller examination of the mineral constituents—metallic and non-metallic,—will be made ere long.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Re-conversion of Heat into Chemical Energy in the production of Gas.*—As is well known, the reaction H_2O(liquid) $+C = H_2 + CO$ is endothermic, the production of water gas from steam and ignited coke absorbing 38770 calories. On the other hand, the reaction $C+O = CO$ is exothermic, the production of generator gas by passing air over excess of ignited coke evolving 29690 calories; the nitrogen being left in the gas. This amount of heat would raise the temperature of the carbon monoxide to 2169°; so that if used at once, the 29690 calories would be utilized. But in general the gas is stored in a holder before use and so is cooled to 15°; thus losing the heat of formation, which is 30·4 per cent of the total heat of combustion of the coke. In order to avoid this loss of energy, Naumann has suggested combining an exothermic with an endothermic reaction and thus storing up the heat energy in the gas itself in the form of chemical energy. This may be done (1) by mixing air and water-vapor together in such proportion that by their mutual action upon

ignited coke, neither absorption nor evolution of heat will take place; producing a water generator gas, as in the Dowson process. Or (2) by mixing the air with carbon dioxide before passing it over the ignited coke; the reaction $CO_2+C=(CO)_2$, being endothermic, 38270 calories being absorbed, and the resulting product being a carbon-dioxide generator gas. The author gives the composition of gases thus prepared, and compares them together, with respect (A) to the heat of combustion of one liter of the gas, calculated from composition, (B) to the calorific intensity, so calculated, and (C) to the specific heat of the combustion-products of the gas; i. e. the heat evolved by one liter of these combustion products when cooled 1°. These results are as follows:

Gas.	A.	B.	C.
1. Generator gas	1044 cal.	1904°	0·5487 cal.
2. Carbon-dioxide gas	1739 "	2449	0·7101 "
3. Water generator gas (liquid water at 15°)	1652 "	2356	0·7016 "
4. " " " (water-vapor at 15°)	1790 "	2431	0·7363 "
5. Water gas	2812 "	2830	0·9934 "

—*Ber. Berl. Chem. Ges.*, xxv, 556; *J. Chem. Soc.*, lxii, 673, June, 1892. G. F. B.

2. *On the Temperature of Ignition of Electrolytic Gas.*—More than a year ago Krause and V. Meyer showed that electrolytic gas, slowly passed through a glass tube immersed in boiling stannous chloride, at 606°, does not explode. Freyer and V. Meyer have now repeated this experiment using other liquids of higher boiling points. The bath was of sheet iron, in the form of a crucible, and was 10 cm. high and 6 cm. in diameter. Through the cover passed a sheet-iron tube 2 cm. in diameter closed at its lower end and extending nearly to the bottom of the vessel. Outside this tube was half a kilogram of zinc chloride. Within the tube a cylindrical glass bulb was placed, connected by capillary tubes with the gas-evolution apparatus and with a water trough. The zinc chloride was heated to boiling, the temperature rising to redness. On passing the electrolytic gas through the bulb, explosion took place at once, and this, whether the gas was moist or dry. By means of an air thermometer constructed of platinum, the temperature of the boiling zinc chloride was fixed at 730°. The experiment was then repeated with zinc bromide and it was found that the explosion did not take place in actively boiling zinc bromide, the boiling point of which was found to be 650°. Hence the ignition point of electrolytic gas lies between 650° and 730°. The authors observed that the explosion in the zinc chloride takes place with certainty only when the gas is introduced into the chloride in active ebullition. If it be passed through below the boiling point and then the temperature be raised to 730°, a slow union takes place, forming water.—*Ber. Berl. Chem. Ges.*, xxv, 622; *J. Chem. Soc.*, lxii, 680, June, 1892. G. F. B.

3. *On the Electromotive Activity of the Ions.*—In 1890, Nernst and Planck deduced the electromotive forces between liquids

from the osmotic pressure and dissociation hypothesis. NERNST and PAULI have now determined experimentally the electromotive forces produced in liquid cells made by the combination of decinormal and centinormal solutions of potassium chloride and hydrogen chloride and have compared their results with those obtained from theory in 1890. The agreement between theory and observation is quite satisfactory. Consequently it follows that, since solutions of zinc sulphate and of copper sulphate having equal molecular concentrations, are both very nearly dissociated into ions, there should be no considerable electromotive force at their surface of contact. Now on investigating the combination

$$Hg \mid HgSO_4 \mid 1/10n\ CuSO_4 \mid 1/10n\ ZnSO_4 \mid HgSO_4 \mid Hg$$

the authors have found that in fact the electromotive force developed is only ·00024 volt. Hence the contact of the two liquids in a Daniell cell is not the seat of an appreciable electromotive force. —*Ann. Phys. Chem.*, II, xlv, 353; *J. Chem. Soc.*, xlii, 671, June, 1892. G. F. B.

4. *On the Separation of Precipitates at the Surface bounding Electrolytes.*—It was long ago observed by Faraday that if a saturated solution of magnesium sulphate be placed in the bend of a U-tube and a layer of water be placed in each limb of the tube resting upon the sulphate, so that the two liquids do not mix, then on passing a current through the whole, a precipitation of magnesium hydroxide takes place at the surface which separates the sulphate from the water containing the negative electrode. In 1887, Herrmann repeated these experiments with zinc sulphate. KÜMMELL has now investigated the matter more thoroughly, using in place of aqueous solutions of the metallic sulphates, solutions prepared with sufficient gelatin so that they solidify on cooling. The presence of the gelatin does not interfere with the phenomenon in question while at the same time it prevents the admixture of the solution and the water, which it is not easy to prevent otherwise. Experimenting in this way, he found that of the many sulphates examined, the precipitation occurred only with those of magnesium, zinc, cadmium and aluminum. The separation of the hydroxide always takes place first, at the negative electrode itself; the appearance of the precipitate at the boundary of the two liquids taking place later. By modifying suitably the method of experimenting it was ascertained that the phenomenon is due to a transfer of the solid particles from the negative electrode through the feebly conducting water by the electric current.—*Ann. Phys. Chem.*, II, xlvi, 105; *J. Chem. Soc.*, xlii, 1038, Sept., 1892. G. F. B.

5. *On Chemical Phenomena at low Temperatures.*—PICTET has experimented on the chemical and physical phenomena observable at very low temperatures. He finds that by means of powerful compressors and aspirators, a mixture of sulphur dioxide and carbon dioxide will give a temperature of −110°, nitrogen

monoxide and ethylene about −150°, and air a minimum temperature of −210° to −213°. These low temperatures were measured with a dry hydrogen thermometer, or by alcohol or ether thermometers, verified by the hydrogen thermometer. The author observes that the very long radiant waves emitted at these very low temperatures pass readily through almost all bodies. Thus a vessel at −110° for example will cool with practically the same rapidity whether the layer of cotton enveloping it be 50^{cm} or 10^{cm} or only 2^{cm} in thickness. Moreover, he finds that when chloroform is immersed in nitrogen monoxide at −120°, a thermometer placed in it sinks to −68·5° and crystallization begins. If transferred to a mixture of carbon dioxide and sulphur dioxide at −80°, the thermometer falls to −80° and the crystals of chloroform melt again. Replaced in the nitrogen monoxide at −120°, the thermometer rises to −68·5° and crystallization begins again. At −83·5° the crystals remain stationary increasing when the temperature falls and melting when it rises. Since crystallization takes place on the inner wall when the vessel is cooled at −120° it seems probable that the thermometer in the middle is affected by the heat of crystallization and at −68·5° is in dynamic equilibrium with the medium in which it is immersed. At −80° no crystals are formed and the thermometer is affected by radiation only.—*C. R.*, cxiv, 1245; *J. Chem. Soc.*, lxii, 1138, October, 1892. G. F. B.

6. *The new Telephotographic lens.*—This invention of T. R. Dallmeyer makes it possible to obtain large pictures of objects situated at long distances by short exposures. The anterior element of his combination of lenses is a positive lens of large aperture and short focus, while the posterior is a negative and of fractional part of the focal length of the former lens. One is reminded of the principle of the Galilean telescope, with this difference, that the emergent rays are convergent and not divergent. The size of an image thrown on a screen can be varied at will by altering the distance between the elements. The farther the lens is from the focussing screen the longer will be the time of exposure. Some pictures taken by this lens were exhibited at a meeting of the Camera Club in London. One picture represented a building at a distance of 500 yards. The telephotographic lens, with 30 inches extension, represented the house as 6$\frac{1}{2}$ inches long, while a rapid rectilinear lens, with extension of 14 inches, gave the house as $\frac{3}{4}$ inch long.—*Nature*, p. 161, Dec. 15, 1892.

J. T.

7. *Oxygen for lime light.*—The oxygen gas obtained from atmospheric air by what is known as the Brin process, gives on an average a purity of 95 per cent oxygen. T. C. Hepworth in a letter to *Nature*, has compared the performance of this gas in a lime light with an impure gas containing only 60·6 per cent oxygen. The light afforded by the impure oxygen was about one-half as intense as the light given by the purer oxygen. With the good oxygen the lime cylinder was quickly fitted, while with

the other it showed no signs of destruction.—*Nature*, p. 177, Dec. 22, 1892. J. T.

8. *Interference of Electric Waves.*—A Ruhmkorf coil was made to vibrate 130 times per second by means of a thermopile. To one of its terminals was attached a copper wire ending in a hook, to which a linen thread soaked in calcium chloride was attached by one end, the other hanging free. One of the terminals of a telephone was placed in contact with the thread, the other being isolated. The sound in a telephone was completely extinguished at a certain distance from the copper. When both ends of the thread (which was 3^m long), were connected by fine copper wires, two points of extinction were reached, one from each end. On shortening the thread these points approached each other and formed a zone of extinction between them. This zone of extinction spread over the entire copper wire as the thread was shortened to zero. The neutral zone is due to interference of two waves of the same period and of equal potential meeting in opposite directions.—*Comptes Rendus*, Nov. 14, 1892, *Nature*, Nov. 24, 1892. J. T.

9. *Explanation of Hall's phenomenon.*—E. Lommel in a preliminary notice, states that by means of a suitably strong current, magnetic filings sprinkled upon a conducting plate will arrange themselves so as to form a beautiful representation of the equipotential lines of the current. When this conducting plate is brought into a magnetic field these magnetic force lines alter in length and the stream lines of the current, perpendicular to the magnetic force lines, also change, and in these changes can be found an explanation of the Hall phenomenon.—*Ann. der Physik*, No. 12, 1892, p. 766. J. T.

10. *A Mercury Voltaic arc.*—H. Avon has succeeded in producing a mercury vapor light, of great intensity, by suitably inclining a column of mercury held in a Ω shaped tube which is connected at its point of greatest curvature with a straight tube which is provided with a T-shaped connection, which allows connections to a manometer and to an air pump. When the column of mercury in the inverted U-tube is caused to separate at its bending by a slight shock a Voltaic arc results at this point which fills the whole section of the tube with an extraordinarily intense light. Avon gives a list of the spectrum lines which he has measured by means of this light. In addition to the thirteen lines measured by Kayser and Runge, he finds twenty more.—*Proceedings of the Physical Society of Berlin*, Oct. 21, 1892, *Ann. der Physik und Chem.*, No. 12, 1892, p. 767. J. T.

II. Geology and Natural History.

1. *North American Fossil Mammals.*—Volume iv, of the Bulletin of the American Museum of Natural History, just completed, contains the following important papers on Fossil Mammals:—

Fossil Mammals of the Wasatch and Wind River beds, (collection of 1891), by H. F. Osborn and J. L. Wortman, covering 68

pages.—The paper contains valuable notes on several of the species of these beds. The facts with regard to the Creodont, *Palæonictis occidentalis* are illustrated by a large plate showing the jaws and teeth; and figures of the dentition of Pachyæna and other genera are contained in the text. Coryphodon is described as being plantigrade behind while digitigrade in the forefeet, and figures are given. The skull of *Systemodon tapirinus* is represented. These are a few of the many points brought out.

Revision of the Species of Coryphodon, by CHARLES EARLE. For the preparation of this paper Mr. Earle had access to the collections of the American Museum of Natural History, and the collection of Coryphodon remains of Prof. Cope which was liberally placed at the author's disposal. The number of species which had previously been described is twenty-one, seven of these under the genus Coryphodon, ten under Bathmodon, two pertaining to Metalophodon, and one to each Manteodon and Ectacodon. All were described by Cope except one species of Coryphodon, *C. hamatus* of Marsh. The study of the specimens by Mr. Earle has led him to reduce the number of species to ten; *Coryphodon radians*, *C. testis*, *C. elephantopus*, *C. cuspidatus*, *C. hamatus*, *C. obliquus*, *C. curvicristis*, *C. anax*, *Manteodon subquadratus* and *Ectacodon cinctus*. He expresses doubt with regard to *C. hamatus*, as he had not seen the specimen.

Characters of Protoceras (Marsh), *the new Artiodactyl from the Lower Miocene*, by H. F. OSBORN and J. L. WORTMAN.—The specimens of this horned Artiodactyl belong to the species *P. celer* of Marsh. The collections of Prof. Marsh include a female skull, and those of the American Museum a male. Both are here described and figured, and also the bones of the fore and hind feet. The *Protoceras celer* was made the type of a new family by Marsh; and this view is sustained by the authors. They place the family between the Tragulina and the Pecora. From the latter they are widely different, having no marked affinities in the direction of either of the families, the Giraffidæ, Cervidæ or Bovidæ. From the former the divergence is less great, but instead of having no horns, they have multiple horns, there being paired bony protuberances on the parietals, frontals and maxillaries, besides having several other important points of difference. The number of these bony protuberances on the cranium is ten. These protuberances however are not horn-cores, but had a dermal covering. "The grotesque appearance is heightened by the large canines, which give the lateral aspect of the skull a decided suggestion of resemblance to that of the Uintatherium."

The Proceedings of the Academy of Natural Sciences of Philadelphia for August, 1892, contains (pp. 291–323) a "*Revision of the North American Creodonta*" by W. B. SCOTT, with notes on some genera which have been referred to that group, based chiefly on the large collection of Professor Cope. The following provisional families are described: Oxyclænidæ, Arctocyonidæ,

Triisodontidæ, Mesonychidæ, Proviverridæ, Hyænodontidæ, Palæonictidæ, Miacidæ; and then notes follow on the genera referred to these groups.

The same volume of the Proceedings of the Academy (p. 326) contains a note by Prof. COPE on the discovery of remains of *Hyæna* and other Carnivores in the Pliocene Blanco beds on the Llano Estacado in western Texas. The Hyæna—the first found in America—is named the *Borophagus diversidens*. One of the other Carnivores, is a Weasel, and is named by Prof. Cope *Canimartes Cumminsii*, after its discoverer; and a third, *Felis Hillianus*, after Prof. R. T. Hill.

Memoir on the Genus Palæosyops of Leidy and its allies, by CHARLES EARLE. pp. 267–388, 4to, of the Journal of the Academy of Natural Sciences of Philadelphia, vol. ix (Oct., 1892).—This able monograph on the genus *Palæosyops*, 120 pages in length and illustrated by five plates, is based on the study of the collections of the Philadelphia Academy, those of Prof. Cope, others of the Princeton Museum, and specimens in the Yale College Museum. The Princeton collections, obtained in four expeditions to the region under the leadership of Professors Scott and Osborn, are especially large, and have enabled the author to add to his many excellent illustrations a restoration of Leidy's *Palæosyops paludosus*. With regard to the relations of the genus, he says: "I think that *Palæosyops* and the allied genera, *Diplacodon*, and *Titanotherium*, should be placed in "the family Titanotheriidæ." As the prefatory remarks state, "the association of the renowned name of Dr. Joseph Leidy with this genus gives to these investigations especial interest at the present time."

2. *Geology of the Eureka District*, by ARNOLD HAGUE. 396 pp. 4to, with 8 plates and a folio Atlas of 13 plates. Volume XX, of the Memoirs of the U. S. Geological Survey.—This volume, besides treating of the general geology and ores of the Eureka region, discusses at length the nature and origin of its igneous rocks. The system of flexures and faults in the rocks is referred to time after the Carboniferous and before the close of the Jurassic period. No Mesozoic rocks occur in the region. The igneous rocks are termed volcanic; but no volcanoes are reported; instead, the eruptions were along the old faults of the region, and through fissures made at the time of the eruptions. The ejection of the andesites and rhyolites was followed by the deposition of the ores, and the latter are stated to have come up from below as the result of solfataric action which accompanied the igneous action, but as having become more or less changed into different kinds, and distributed by the prolonged continuance of this action.

The final conclusions of the author as to the relations and origin of the igneous rocks, are presented in a closing summary as follows (p. 289).

The Eureka District presents a most instructive volcanic region standing quite apart from all other centers of similar eruption, yet, in the nature of its extravasated material, typical of many localities in the Great Basin.

The region offers no direct proof of the age of volcanic energy; yet all evidence points to the conclusion that the eruptions belong to the Tertiary era and for the most part to the Pliocene period. They may have extended well on into Quaternary time, although there is no reason to suppose that eruptions took place within historic time.

As regards their mode of occurrence the principal eruptions may be classed under four heads: First, they broke out through profound fissures along the three great meridional lines of displacement, the Hoosac, Pinto, and Rescue faults, and to some extent along the lesser parallel faults; second, following the lines of orographic fracture, they border and almost completely encircle the large uplifted masses of sedimentary strata like the Silverado and County Peak block and the depressed Carboniferous block between the Hoosac and Pinto faults; third, they occur in numerous dikes penetrating the limestone; fourth, they occur in one or two relatively large bodies, notably Richmond Mountain and Pinto Peak, along lines of displacement already mentioned.

All the lavas may be classed under the heads: hornblende-andesite, hornblende-mica-andesite, dacite, rhyolite, pyroxene-andesite, and basalt. They pass by insensible gradations from one to the other. All division lines are more or less arbitrary; they are necessary for the purposes of classification, although they may not exist in nature.

Field observations clearly show that the order of succession of these natural groups into which the lavas have been divided was as follows: First, that the hornblende-andesite was the earliest of all the erupted material; second, that the hornblende-mica-andesite followed the hornblende-andesite; third, that the dacite followed the hornblende-mica-andesite; fourth, that the rhyolite closely followed the dacite; fifth, that the pyroxene-andesite succeeded the rhyolite; sixth, that the basalt was the most recent of all these volcanic products.

In chemical composition this entire series of lavas shows a range in silica amounting to about 25 per cent, a range which is quite as wide as is usually found in most centers of eruption even where the volume of lavas thrown out is vastly greater and the duration of volcanic energy far longer. Analyses show endless transition-products between the extreme basic and acidic lavas, with a tendency of the alkalies and silica to accumulate at the acidic end and the material forming the ferro-magnesian minerals at the basic end.

It is maintained in this work that all the varied products of eruption are derived from a common source, a homogeneous molten mass. Under a process of differentiation this earlier mass split up into two magmas, designated as a feldspathic and a pyroxenic magma. The lavas at Eureka are the result of the same process of differentiation derived from one or the other of these magmas. Beginning with hornblende-andesite, the earliest lava, the feldspathic magma became more siliceous until the close

of rhyolitic eruptions. The rhyolite was followed by pyroxene-andesite and the eruptions became more and more basic until the close of the volcanic period. The feldspathic and pyroxenic lavas do not approach each other in their tenure of silica within 2·25 per cent. In chemical composition the earliest eruptions of both magmas resemble each other, but from this common ground they differentiate steadily until the feldspathic reaches the extreme acidic, and the pyroxenic the extreme basic end of their respective series. The extreme products of differentiation in any volcanic center in the Great Basin are rhyolite and basalt.

3. *Geological Survey of Alabama*, Prof. E. A. Smith, the State Geologist, has recently issued a brief sketch of the Geology of Alabama, occupying 36 octavo pages. There has been published also Bulletin No. 4, of the Alabama Survey, consisting of a Report on the Geology of Northeastern Alabama and adjacent portions of Georgia and Tennessee, by C. Willard Hayes, Assist. Geol. U. S. G. S., which describes the rocks and the orographic structure of the region, gives figures of the flexures and faults, and closes with an excellent colored map showing the distribution of the Paleozoic formations from the Cambrian upward.

4. *Geological Atlas of the United States, Chattanooga sheet, Tennessee.*—A large folio brochure, consisting of 6 pages of text and 4 maps, has just been published by the United States Geological Survey. The maps include a topographical map of the region, two detailed geological maps in colors, and one sheet of sections. The area represented covers about 100 square miles. The size of the maps is 14½ by 17½ inches. The work is in the best style as regards the exhibition of the geological formations, and is also faultless esthetically. The charts are the commencement of a series, already far advanced as regards geological investigation, which has in view the representation of the geological structure of the Appalachian region. The names of the geologists mentioned on the charts are G. K. Gilbert, Chief Geologist, Bailey Willis, Geologist-in-charge, and Geology by C. Willard Hayes.

5. *The North American Continent during Cambrian Time*, by C. D. Walcott. From the 12th Report of the Director of the U. S. Geological Survey, for 1890–91, pp. 529–568.—Mr. Walcott here exhibits in an instructive way by maps and descriptions his results as to the geographical condition of Cambrian North America.

6. *The Lafayette Formation*, by W. J. McGee, Ibid., pp., 351–521.—This paper is a very full exhibition of the characters and distribution of the Lafayette formation. The latter subject is presented on a colored geological map, which exhibits also the author's views as to the distribution of the Columbian formation.

7. *The Origin and Nature of Soils*, by N. S. Shaler, Ibid. pp. 217–346.—Professor Shaler considers the subject of soils from a geological point of view. The sources of soils are explained, their various characteristics, the processes by which they have been formed over regions of diverse conditions, and the geological

agencies, living and physical, concerned in modifying them, and many fine plates illustrate the topics discussed. The paper closes with observations on the action and reaction of man and the soil.

8. *Cambrian Fossils of New Brunswick.*—Bulletin of the Natural History Society of New Brunswick, No. X, St. John, N. B., contains a paper on *Protolenus*, a new genus of Cambrian Trilobites from the St. John group, by G. F. MATTHEW. The same genus is described by Mr. Matthew and two species figured in the Canadian Record of Science for October, 1892.

9. *Experiments in Physical Geology.*—Professor ED. REYER of Vienna has lately issued three interesting brochures upon subjects in physical geology. They are entitled: Ursachen der Deformationen und der Gebirgsbildung (pp. 40); Geologische und Geographische Experimente, Heft I, Deformation und Gebirgsbildung (pp. 52); Heft II, Vulkanische und Massen-Emptionen (pp. 55, Wm. Engelmann, Leipzig.) The first named is a general statement of conclusions based on the experiments which are very thoroughly illustrated in the last two. The subject is treated in the form of a discussion of several hypotheses to explain mountain-making. These are: I, Changes of substance as by oxidation, hydration, solution, etc.; II, Contraction of the earth; III, Differences of density; IV, Loading or as it is termed the "Onerar-hypothesis;" V, Hypotheses based on heat; VI, Deformations due to eruptions. The author's wide experience in many regions of geological disturbance and of igneous activity enables him to throw much light upon the subject treated. The numerous experiments were made on small models, which were compressed in the usual way with a screw. Materials of varying firmness were employed, so as to represent both stiff and yielding strata. The results of the successive steps in each experiment are liberally illustrated, so that the application to the similar cases in nature are obvious, almost without the verbal explanation. J. F. K.

10. *Brief notices of some recently described minerals.*—GEIKIELITE and BADDELEYITE are two species described by Fletcher as occurring in the form of pebbles in the gem washings near Rakwana, Ceylon.

Geikielite shows two cleavages at right angles to each other, one of them perfect. It has a splendent metallic luster and bluish black color, though thin cleavage flakes have a purplish red tint. The hardness is 6·5 and specific gravity 3·98. An analysis shows it to be a magnesium titanate, $MgTiO_3$, corresponding to perovskite, $CaTiO_3$.

Baddeleyite resembles columbite in general aspect and has a specific gravity of 6·02 and hardness of 6·5; the crystallization is probably monoclinic. In composition it is also highly interesting, it consisting of zirconia, ZrO_2, an oxide not before found among minerals but whose existence in nature was to have been anticipated.—*Nature*, Oct. 27, 1892.

BRAZILITE is described by Hussak from the granular pyroxenic rock called jacupirangite at the iron mine of Jacupiranga, Brazil.

It occurs in monoclinic crystals tabular parallel to a (100); they are usually twins and often complex. The color is yellow to dark brown, the luster greasy to vitreous, the hardness 6·5, and the specific gravity 5·006. It is announced as a tantalo-niobate probably near to yttrotantalite, but the author (priv. contrib.) has stated later that Prof. Blomstrand finds it to consist of zirconia; it hence is to be united with baddeleyite. (Jahrb. Min., ii, 141, 1892,). Fletcher (letter of Jan. 7) suggests that the original qualitative tests may have been made upon a different mineral, from that described crystallographically and analyzed by Blomstrand.

FOLGERITE, BLUEITE, WHARTONITE.—Dr. Stephen H. Emmens has recently given (Jour. Amer. Chem. Soc., xiv, No. 7) the results of an examination of some nickel minerals from the Sudbury district, Algoma, Ontario, to which the above names have been given.

Folgerite occurs massive with a light bronze-yellow color and grayish black streak; specific gravity 4·73; hardness 3·5; non-magnetic. One of three analysis is given below (I), the composition corresponds to $NiFeS_2$ or intermediate between millerite and pentlandite. It is named after Commodore W. M. Folger of the U. S. Navy.

Blueite occurs massive with olive-gray to bronze color, black streak, specific gravity 4·2 and hardness 3 to 3·5; it is non-magnetic. An analysis (deducting gangue) is given under II below; in composition it is a nickeliferous pyrite with Fe : Ni = 12 : 1, though it differs in being easily soluble in nitric acid without separation of sulphur. It is named after Mr. Archibald Blue, now Director of the Bureau of Mines of Ontario.

Whartonite occurs in cellular form with granular structure, the cavities being lined with minute cubic crystals; color bronze-yellow, streak black; hardness 4 and specific gravity 3·73: About 10 p. c. of the fine powder was found to be magnetic and the analysis leads to the conclusion that it is a mixture of a nickel-iron disulphide with some magnetite; deducting the latter the results in III are obtained, corresponding to $(Fe, Ni)S_2$ with Fe : Ni = 7 : 1. It is named after Mr. Joseph Wharton, of Camden, N. J.

The analyses are as follows:

		S	Fe	Ni
I.	*Folgerite*	31·10	33·70	35·20 = 100
II.	*Blueite*	55·29	41·01	3·70 = 100
III.	*Whartonite*	52·29	41·44	6·27 = 100

To these analyses of the Sudbury nickel ores may be added those quoted in Dana's Mineralogy (1892, pp. 65, 74, 75), also those by Hoffmann mentioned in the January number (p. 76); it can hardly be supposed that all of these ores are distinct homogeneous minerals.

NICKEL-SKUTTERUDITE. A gray metallic mineral of granular structure occurring in silver ore (native silver) near Silver City,

New Mexico, is described by E. Waller and A. J. Moses. It has a hardness of about 5, gray color and black streak. An analysis, after deducting 4·56 of SiO_2 and 8·38 silver gave the results below; these correspond to RAs_2 with R = Ni : Co : Fe = 4 : 2 : 1, or skutterudite in which the cobalt is largely replaced by nickel.

As	Ni	Co	Fe
78·67	12·25	6·16	2·92 = 100

—*School of Mines Quarterly*, vol. xiv, No. 1.

HAUCHECORNITE is a nickel-bismuth mineral described by Scheibe from the Friedrich mine in the Hamm mining district, Germany. It occurs in tetragonal crystals and massive of a light bronze-yellow color; hardness 5, specific gravity 6·4. Analyses by R. Fischer and others gave discordant results because of the want of homogeneity of the material, but the conclusion is reached that the composition is essentially Ni(Bi,Sb,S). —*Jahrb. Preus. Geol. Landesaustalt*, 1891, p. 91.

CUPROCASSITERITE.—A note upon this supposed new tin mineral from the Black Hills is given by Titus Ulke in the Transactions of the American Institute of Mining Engineers; a further critical investigation is given by Headden on p. 108 of this number.

11. *Large Variations in the Metamorphosis of the same species.*—An elaborate memoir entitled, *The Embryology and Metamorphosis of the Macroura*, by W. K. BROOKS and F. H. HERRICK, makes 140 pages quarto of the fifth volume of the Memoirs of the U. S. National Academy of Sciences, and is illustrated by 57 plates. The species microscopically investigated and here reported upon are of the genera *Gonodactylus Alpheus* and *Stenopus*. The authors mention, in the introductory pages, as one remarkable result of their study of the genus Alpheus, the discovery that while the larval stages of different species are similar, the individuals of a single species sometimes differ more from each other as regards their metamorphoses than the individuals of two very distinct species, and make on this point the following remarks:

This phenomenon has been observed by us and carefully studied in two species—*Alpheus heterochelis* and *Alpheus Saulcyi* —and it is described in detail, with ample illustrations, in the chapter on the metamorphosis of Alpheus. In the case of the first species the difference seems to be geographical, for while all the individuals which live in the same locality pass through the same series of larval stages, the life history of those which are found at Key West is very different from that of those which live on the coast of North Carolina, while those which we studied in the Bahama Islands present still another life history. In the case of the second species—*Alpheus Saulcyi*—the difference stands in direct relation to the conditions of life. The individuals of this species inhabit the tubes and chambers of two species of sponges which are often found growing on the same reef, and the metamorphosis of those which live in one of these sponges is

sometimes different from that of those which inhabit the other. In this species the adults also are different from each other, but as we found a perfect series of transitional forms there is no good reason for regarding them as specifically distinct; and in the case of the other species—*Alpheus heterochelis*—we were unable, after the most thorough and minute comparison, to find any difference whatever between adults from North Carolina and those from the Bahama Islands, although their life histories exhibit a most surprising lack of agreement. In fact, the early stages in the life of *Alpheus heterochelis* in the Bahama Islands differ much less from those of *Alpheus minor* or *Alpheus Normani* than they do from those of the North Carolina *Alpheus heterochelis;* and, according to Packard, the Key West *heterochelis* presents still another life history.

In the summer of 1881 I received the American Naturalist with Packard's very brief abstract of his observations at Key West upon the development of *Alpheus heterochelis*, and read with great surprise his statement that this species has no metamorphosis, since, while still inside the egg, it has all the essential characteristics of the adult. As I had under my microscope at Beaufort on the very day when I read his account a newly hatched larva of the same species and was engaged in making drawings to illustrate the metamorphosis of which he denies the existence, and as my experience in the study of other Crustacea had taught me that all the larvæ of a species at the same age are apparently facsimiles of each other down to the smallest hair, Packard's account seemed absolutely incredible, and I hastily decided that, inasmuch as it was without illustrations and was written from notes made many years before, it involved some serious error and was unworthy of acceptance. This hasty verdict I now believe to have been unjust, since my wider acquaintance with the genus has brought to my notice other instances of equally great diversity between the larvæ of different specimens of a single species.

The phenomenon is, however, a highly remarkable one and worthy the most thorough examination, for it is a most surprising departure from one of the established laws of embryology—the law that the embryonic and larval stages of animals best exhibit their fundamental affinities and general resemblances, while their specific characteristics and individual peculiarities make their appearance later.

This is one of the important subjects illustrated in the following descriptions.

12. *Morphologische Studien* von K. Schumann. 1te Abtheilung. —206 pp., 6 Tafeln. 8vo. Leipzig, 1892 (Wm. Engelmann.)—Prof. Karl Schumann has just published the first part of his "Morphologische Studien," in continuance of his investigations into the anatomy of the flower. These studies will concern themselves not only with flower-structure but also with the anatomy of flowering plants in general, along the lines laid down by Hofmeister in his "Allgemeine Morphologie." The first half of this part, therefore, is

devoted to a discussion of phyllotaxy. The arrangement of leaves in spiral lines is first considered and then the various published views upon this topic are discussed with some fullness. Schumann passes in review Braun's work in establishing the study of phyllotaxy upon a scientific basis, Hofmeister's effort to explain the spiral arrangement by the fact that new organs are formed in the largest gaps left between organs already formed, Schwendener's success in demonstrating the mechanical basis for phyllotaxy, and Sachs's theory that the spiral lines, e. g. in the Screw-Pine, are produced by torsion during the growth of the axis. He, himself, points out that the arrangement of leaves in straight or spiral ranks is intimately connected with the symmetrical or asymmetrical development of the sheathing bases of the leaf, which make their appearance upon the growing point of the plant before the leaves do. This relation holds true in all Monocotyledons and most Dicotyledons. In the second half, the special morphology of the genus *Adoxa* and of the Cohort *Fluviales* is discussed in support of this view. W. A. S.

III. Miscellaneous Scientific Intelligence.

1. *Bulletin from the Laboratories of the State University of Iowa.* Vol. II, No. 2.—This number of the Iowa Bulletin opens with a long paper on the Myxomycetes of Eastern Iowa by T. H. McBride, with ten beautiful plates from drawings by Miss Mary P. McBride. It also contains four important paleontological papers by S. S. Calvin; a paper by B. Shimek on the identity of *Pyrgula scalariformis* with *P. Mississippiensis*, and its occurrence, with other species, in the lœss of the Mississippi, but known only in the fossil state; and Notes on Karyokinesis, by L. B. Elliott. Prof. Calvin reports on fossils from the Lower Magnesian limestone of Northeastern Iowa, showing their relations to those of the Calciferous of New York.

2. *Astronomical Journal Prizes.*—Two prizes of two hundred dollars each, in a gold medal or in money, are offered in the *Astronomical Journal*, No. 284, to be awarded to resident citizens of the United States. Details of the conditions are given in the *Astr. Journal.*

The first will be given for the best series of determinations of the positions of comets during the year ending March 31st, 1894: —the second for the best discussion of the path of a periodic comet, the investigation to be made within the two years next preceding Sept. 1, 1894.

3. *Ostwald's Klassiker der Exakten Wissenschaften.*—A notice of this valuable series was given in the January number of this Journal; the three following volumes have just been issued:

No. 38. Photochemische Untersuchungen von R. Bunsen and H. E. Roscoe. (1855–59). Zweite Hälfte.

No. 39. Die in der Atmosphäre vorhandenen organisirten Körperchen: Prüfung der Lehre von der Urzeugung von L. Pasteur (1862).

No. 40. Zwei Abhandlungen über die Wärme von A. L. Lavoisier und P. S. DeLaplace (1780 u. 1784).

APPENDIX

ART. XXII.—*Restoration of Anchisaurus;* by O. C. MARSH. (With Plate VI.)

THE Triassic Dinosaurs now known from the Connecticut river sandstone have been investigated by the writer, and some of the results have already been placed on record in this Journal.* Remains of five individuals have been discovered, sufficiently well preserved to indicate the main characters of the animals to which they pertained. These were all carnivorous forms of moderate size, and the known remains are from essentially the same geological horizon. Many larger forms, probably herbivorous, are indicated by footprints, but no characteristic portions of the skeleton have yet been found.

The genus *Anchisaurus*, one of the oldest known members of the *Theropoda*, is so well represented by parts of four skeletons, two nearly complete, from these deposits, that a restoration of one species can now be made with considerable certainty. This has been attempted, and the result is given, one-twelfth natural size, in the accompanying plate. The animal when alive was about six feet in length.

The skeleton chosen for this restoration is the type specimen of *Anchisaurus colurus*, already described by the writer. This skeleton when discovered was entire, and apparently in the position in which the animal died. Portions of the neck and the tail vertebræ were unfortunately lost before the importance of the specimen was realized, but the skull and nearly all the rest of the skeleton were saved. From these the matrix in great part has been removed, so that the more important characters can be made out with certainty. The parts missing are fortunately preserved in a smaller specimen of an allied species (*Anchisaurus solus*) found at the same locality, and these have been used to complete the outline of the restoration. Portions of two other specimens, nearly allied, and from the same horizon, were also available, and furnished some suggestions of value.

The restoration as shown on Plate VI. indicates that *Anchisaurus colurus* was one of the most slender and delicate dinosaurs yet discovered, being only surpassed in this respect by some of the smaller bird-like forms of the Jurassic. The

* This Journal, vol. xxxvii, p. 331, April, 1889; vol. xlii, p. 267, September, 1891; and vol. xliii, p. 543, June, 1892.

position chosen is one that must have been habitually assumed by the animal during life, but the comparatively large fore limbs suggest the possibility of motion on all four feet. The compressed terminal digits of the fore feet, however, must have been covered by very sharp claws, which were used mainly for prehension, and not for locomotion.

The small head and bird-like neck are especially noticeable. The ribs of the neck and trunk are very slender. The tail apparently differed from that of any other dinosaur hitherto described, as it was evidently quite slender and flexible. The short neural spines and the diminutive chevrons directed backward indicate a tail not compressed, but nearly round, and one usually carried free from the ground.

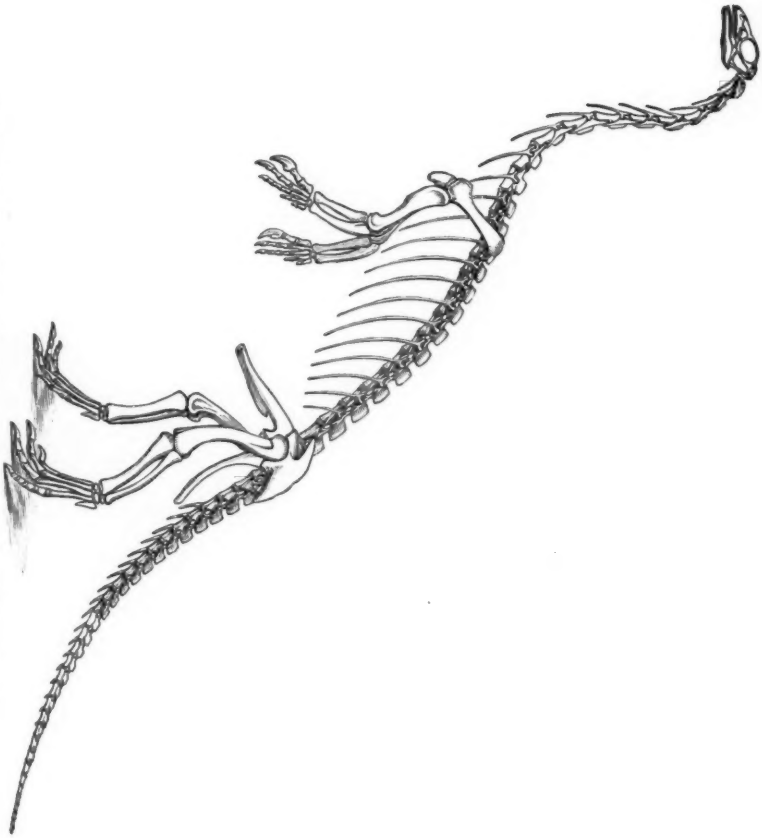
The present restoration will tend to clear up one point long in doubt. The so-called "bird-tracks" of the Connecticut river sandstone have been a fruitful subject of discussion for half a century or more. That some of these were not made by birds has already been clearly demonstrated by finding with them the impressions of fore feet, similar to those made by reptiles. Although no osseous remains were found with them, others have been regarded as footprints of birds, because it was supposed that birds alone could make such series of bipedal, three-toed tracks and leave no impression of a tail.

It is now evident, however, that a dinosaurian reptile like *Anchisaurus* and its near allies must have made footprints very similar to, if not identical with, the "bird tracks" of this horizon. On a firm but moist beach, only three-toed impressions would have been left by the hind feet, and the tail could have been kept free from the ground. On a soft, muddy shore, the claw of the first digit of the hind foot would have left its mark, and perhaps the tail also would have touched the ground. Such additional impressions the writer has observed in various series of typical "bird tracks" in the Connecticut sandstone, and all of them were probably made by dinosaurian reptiles. No tracks of true birds are known in this horizon.

The genus *Ammosaurus*, represented by remains of larger size from the same strata, was a typical carnivorous dinosaur, and apparently a near ally of *Anchisaurus*. So far as at present known, the footprints of the two reptiles would be very similar, differing mainly in size.

The only other reptile known from the Connecticut sandstone by any part of the skeleton is a large *Belodon* from a lower horizon. This crocodilian may be called *Belodon validus*, and will be described by the writer later.

New Haven, Conn., Jan. 21, 1893.



Restoration of ANCHISAURUS COLURUS, Marsh. One-twelfth natural size.